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REVIEW OF LANDSPREADING OF LIQUID MUNICIPAL SEWAGE SLUDGE

BATTELLE COLUMBUS LABORATORIES

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REVIEW OF LAND SPREADING OF LIQUID MUNICIPAL SEWAGE SLUDGE

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The objective of this study was to review and summarize existing information regarding landspreading of liquid municipal sewage sludge. An extensive literature review was conducted and an annotated bibliography is available as a separate report from the NTIS. Emphasis was also given to obtaining information concerning the number of sewage treatment plants currently using landspreading. A questionnaire survey of 1909 sewage treatment plants in Federal Regions 2, 3, 4, 5, and 9 was conducted and selected operations were visited. The information and data gathered during the study are summarized relative to sludge characteristics, sludge handling and distribution systems, economics of landspreading, sludge-soil-plant interactions, public health considerations, land acquisition, and survey of sewage treatment plants. The survey indicated that about 21 percent of the plants in the study regions are using landspreading routinely. Sixty-eight percent of the plants using landspreading have been conducting the practice for less than ten years. Of this 68 percent, over two-thirds have begun the practice only within the last five years.

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This survey of liquid sludge spreading practices was conducted for the Ultimate Disposal Section of the Advanced Waste Treatment Research Laboratory to evaluate the present status and the potential of various techniques of sludge spreading on land for beneficial use and disposal of the sludge. All methods of disposal of pollutants from water involve some risk of causing pollution in another area. Only by comparing the benefits and risks involved in each disposal technique can rational choices between alternatives be made.

A. W. Breidenbach, Ph.D
Director
National Environmental
Research Center, Cincinnati

ABSTRACT

The objective of this study was to review and summarize existing information regarding landspreading of liquid municipal sewage sludge. An extensive literature review was conducted and an annotated bibliography is available as a separate report from the National Technical Information Service. Emphasis was also given to obtaining information concerning the number of sewage treatment plants currently using landspreading. A questionnaire survey of 1909 sewage treatment plants in Federal Regions 2, 3, 4, 5 and 9 was conducted and selected operations were visited.

The information and data gathered during the study are summarized relative to sludge characteristics, sludge handling and distribution systems, economics of landspreading, sludge-soil-plant interactions, public health considerations, land acquisition, and survey of sewage treatment plants. The survey indicated that about 21 percent of the sewage treatment plants in the study regions are using landspreading on a routine basis. Of the plants which are using landspreading, 68 percent of them have been conducting the practice for less than 10 years. Of this 68 percent over 2/3 have begun the practice only within the last 5 years.

This report was submitted in fulfillment of Contract 68-03-0140 by Battelle Memorial Institute, Columbus Laboratories, under the sponsorship of the Environmental Protection Agency. Work was completed as of June, 1974.

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SECTION I

CONCLUSIONS

This report presents a broad overview of landspreading of liquid municipal sewage sludges as an ultimate disposal alternative. Some of the more significant conclusions drawn from the literature review, the survey of sewage treatment plants, and the field visits to active landspreading operations are presented below.

(1) Land disposal of liquid sewage sludges has been practiced for many years in the United States under a wide range of geographic, topographic, climatic, and soil conditions. Although detailed operating documentation is not readily available, the practice has been conducted with apparent success and limited problems.

(2) The principles guiding many of the landspreading operations appear to have evolved from experience gained with sewage farm operations and land disposal activities associated with dried sludge or wastewater effluents.

(3) There is a paucity of easily comparable data specific to liquid sludge from which the overall economic and environmental benefits and costs can be quantified. Specifically, data are generally lacking in regard to sludge composition, application rates, environmental response, and dollar flows.

(4) Most sludge spreading has been done without monitoring the effects upon the environment. Studies are now under way to determine the effects of pathogens, nutrients, trace elements, and other sludge constituents upon soils, water, air, plants, and animals.

(5) Landspreading is a viable sludge disposal alternative. However, criteria for site selection and management techniques need to be developed and disseminated to planning, management, and operational levels.

(6) While liquid sludge has value as a fertilizer, it is not a balanced fertilizer for many crops and soil conditions. Its soil conditioning properties are perhaps more valuable than its fertilizer content. Data derived from statistically meaningful experiments are needed to elucidate and quantify these sludge attributes.

(7) Generally, each plant's landspreading operation will be determined by the sludge composition, transportation factors, soil characteristics, and land use considerations. The purpose of the landspreading operation--disposal only or soil improvement--will help to determine the frequency and rate of application. It will also determine the duration of a land disposal operation at a given site.

(8) Sludges which contain excessive amounts of trace elements and pathogens are potentially dangerous to plants, animals, and public health. Such sludges should not be used as a fertilizer and/or soil conditioner.

(9) Sludge treatment systems designed to eliminate potential problems relative to pathogens are both in operation and research stages. Many problems associated with excessive concentrations of metals and other trace elements could be appreciably reduced by enforcement of stricter controls on industrial discharges to municipal sewers. However, elimination of all metals and other trace elements is not feasible since domestic wastewater contributes a significant amount.

(10) Agricultural land, both cropland and pasture, is most commonly used for landspreading practices. Where such land is not readily available, other lands such as abandoned stripmines, golf courses, parks, highway median strips, forests, orchards, and airports are being used.

(11) There is more than sufficient land area available for landspreading activities. Economical distribution rather than the capacity of the total system to assimilate the sludge is the problem.

(12) The most frequently stated objections to landspreading relate to potential health hazards, nuisances (odors, insects, etc.) associated with the landspreading operation, and a general "human waste stigma". These concerns appear to be more a function of landspreading's visibility as a disposal method than a function of real risk to public health. Well planned public information programs could help to overcome these objections.

(13) Wastewater treatment plant design efforts, both initial and retrofitting, must include considerations of what method will be used for the ultimate disposal of the sludge produced.

(14) Liquid municipal sewage sludge is amenable to land disposal and can offer a number of benefits (i.e., reduced treatment plant operating costs, fertilizer value, soil conditioning

value, supplemental irrigation water) when practiced under the proper conditions. However, problems can result from inappropriate management of this practice. More information should be obtained and guidelines provided relative to safe application rates and frequencies and facility management.

SECTION II

RECOMMENDATIONS

The literature review and field visits to active landspreading operations suggested the following research needs:

(1) Development of methods based upon sewerage service area profiles which will allow the estimation of sludge characteristics and their amenability for land disposal in the liquid state

(2) Development of practical economic and environmental formulae and computational techniques which can be utilized by plant designers and operators to project the costs associated with landspreading

(3) Intensification of field studies to determine the behavior and ultimate fate of these constituents under actual operating conditions, in addition to continuing studies designed to determine allowable soil and plant concentrations of various sludge constituents (for example, heavy metals)

(4) Comparison of the effects of advanced wastewater treatment practices and proposed sludge treatment alternatives to control pathogens on sludge characteristics relative to their amenability for landspreading

(5) Development of programs for disseminating information being developed on landspreading to treatment plant operators, various regulatory agencies, and the general public

(6) Performance of an integrated, multidisciplinary study directed toward an understanding of the complexities of the liquid sludge-soil-plant interactions

(7) Assessment of the feasibility of adopting regional sludge collection and disposal schemes as opposed to independently conducted operations.

SECTION III

INTRODUCTION

One of the primary objectives of the wastewater treatment process is the prevention of water pollution by removing the pollutants from sewage and industrial wastes. The effluent, sludge, and gases produced as by-products of the treatment process must be either disposed of or utilized in an efficient, low-cost fashion without risk to public health and, also, without undue stress on other components of the environment. The traditional means of sludge handling and disposal still widely used today are

- Ocean disposal via barging or pipeline transport
- Dewatering and drying and sale as a fertilizer or disposal in a landfill
- Incineration
- Lagooning
- Landspreading.

Too often, no attempt is made while disposing of sludge to integrate the materials into natural systems. Consequently, much of the conventional disposal technology represents a nonbeneficial use of a potential resource.

The value of human and animal wastes has been recognized for centuries. For instance, the Chinese and other early civilizations applied human organic wastes to the land to improve and/or maintain soil fertility. Many technically advanced European countries including England, France, Poland, and Germany are applying appropriately treated sewage sludge to land surfaces.

The practice of landspreading is increasing in popularity in the United States. Although the initial interests have been directed primarily toward treated wastewater effluents, particularly in water deficient regions, there are many situations where the disposal of the liquid sludge by landspreading is an economical and beneficial solution to the waste-disposal problem.

SECTION IV

OBJECTIVES

The objective of this program was to provide a review and summary of existing information and operational experiences in landspreading of liquid municipal sewage sludge. There was a dearth of information concerning the amount, procedures, and location of sludge applications to the land. Major emphasis was thus given to obtaining information concerning unreported landspreading operations currently employed in this country through a combination questionnaire and telephone survey of all sewage treatment plants greater than $3.8 \times 10^3 M^3$/day (1 mgd) in Federal Regions 2, 3, 4, 5, and 9. In addition, plant visits were made to selected treatment plants and associated landspreading operations.

The collected information was reviewed and summarized with respect to the following aspects:

Sludge Characteristics

Sludge Handling and Distribution Systems

Economics of Landspreading

Sludge-Soil-Plant Interactions

Public Health Considerations

Land Acquisition

Research Needs

Survey of Sewage Treatment Plants.

Each of these aspects is discussed separately in the following sections of this report. An annotated bibliography of the significant literature on landspreading is presented as an appendix to the report.

SECTION V

SLUDGE CHARACTERISTICS

Sludges from municipal wastewater treatment plants vary markedly in moisture content, decomposable organic matter, chemical composition, and microbial populations. Basically, this variability is a result of the composition of the wastewater constituents and treatment plant design and operation.

WASTEWATER CHARACTERISTICS

Generally, wastewater characteristics are responsive to (1) the domestic water system including the water supply source, treatment, and conveyance system; (2) inorganic and organic compounds contained in industrial and domestic wastewaters; and (3) inflow and infiltration into the wastewater collection system.

Each resident of a community is usually considered as the contributor of 265-380 liters of wastewater per day resulting in the production of 91 grams of sludge per day [1]. These values include residential and industrial discharges into municipal wastewater.

The composition of municipal wastewaters is highly dependent on the proportion and nature of the community's industrial base. Extremely variable loadings of industrial wastes to municipal sewage systems will increasingly affect treatment plant operations and ultimately the characteristics of the sludge. Some industrial discharges such as various food and agricultural industry wastes may increase useful landspreading constituents. However, many discharges associated with chemical process, metallurgical, mineral products, petroleum, and wood processing industries may contribute undesirable constituents and as a result may affect sludge disposal practices.

Sludge characteristics are also markedly influenced by the affluency of the municipal residential area served by the wastewater treatment plant. The increasing household use of marketed chemical compounds (cleaning complexes, drugs, etc.) affect sewage treatment operations and, finally, sludges. The increased use of garbage grinders [2] and disposable paper products has increased the solids contributed by households.

The residential diet also affects wastewater and sludge characteristics. As an example, the daily normal digestion and excretion of zinc is

expected to average about 10 mg/person. The concentration of zinc in fresh foods ranges from less than one ppm in fruits to 50 ppm in legumes [3]. Higher amounts of zinc are contained in yeast, mushrooms, and seafoods, with oysters containing as much as 2300 ppm [4].

The design and integrity of the wastewater collection system can also alter sludge characteristics. Treatment plant operations are affected by increased loadings (hydraulic and solid) due to captured urban stormwater runoff (combined sewers and/or groundwater infiltration). Stormwater runoff reaching the sewage treatment plant often transports various "street refuse" (litter, dirt, bird and animal droppings, air pollution fallout particles, oils, chemical compounds, etc.).

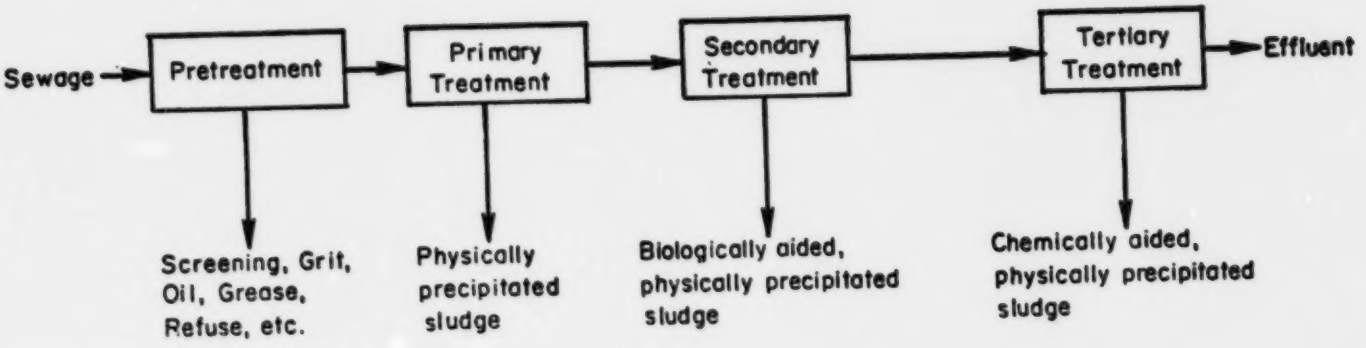
TREATMENT PLANT SLUDGES

Figure 1 is a conceptual schematic diagram of sewage treatment operations that indicates associated general sludge characteristics. In reality, sewage treatment plant design alternatives are numerous, particularly for secondary treatment. In addition, a sewage treatment plant which has been modified to provide secondary and/or tertiary treatment is more likely to resemble the simplistic schematic presented on Figure 2.

Raw sludge usually refers to settled water-borne materials in sedimentation tanks. Primary sludge exhibits a solids content of about 2.5-5.0 percent. These unstabilized sludges are characteristically highly putrescible, with a volatile solids content of 50 to 80 percent, and they contain a high bacterial count [1, 5, 6]. In addition to high concentrations of fecal coliform bacteria (i.e., Escherichia coli about 10^7/100 ml) other intestinal and respiratory tract organisms are present at lower concentrations [7]. Organisms which cause such diseases as cholera, typhoid, dysentery, etc., are also commonly associated with fecal wastes and may be present.

Although some measure of decomposition occurs, secondary sludges are unstabilized. Biological secondary treatment operations, trickling filters, or aerated systems produce sludges with total solids content percents ranging from 5-10 or 0.5-1, respectively. The sludges consist primarily of floc-forming zooglea bacteria which have entrapped suspended solids and adsorbed colloidal material. These sludges are highly putrescible, exhibit a high bacteria count, and volatile solids content normally range from 65-75 percent [1, 5, 6].

The chemicals most commonly used to remove phosphates (lime, alum, and iron salts) produce sludges ranging in total solids content from 5-15 percent after gravity thickening. Chemical sludges from alum or iron coagulation produced by operation of a separate tertiary system result in the formation of sludge material which has a volatile content of about 10 percent. Such materials are slightly to moderately putrescible and contain only minor amounts of bacteria. However, these sludges are not considered of value as fertilizers or soil conditioners. In addition, the high contents of aluminum or iron may be deleterious to soils.



Total solids, percent	2.5 - 5.0	0.5-1.0 Waste activated 5.0-10.0 Trickling filter humus	1.0 - 3.0
Volatile solids, percent	60-80	65-75	≤ 10
Comments	Highly putrescible High bacteria count	Highly putrescible High bacteria count	Moderately nonputrescible Minor - no bacteria count

FIGURE 1. SCHEMATIC OF SEWAGE TREATMENT OPERATIONS AND GENERAL SLUDGE CHARACTERISTICS

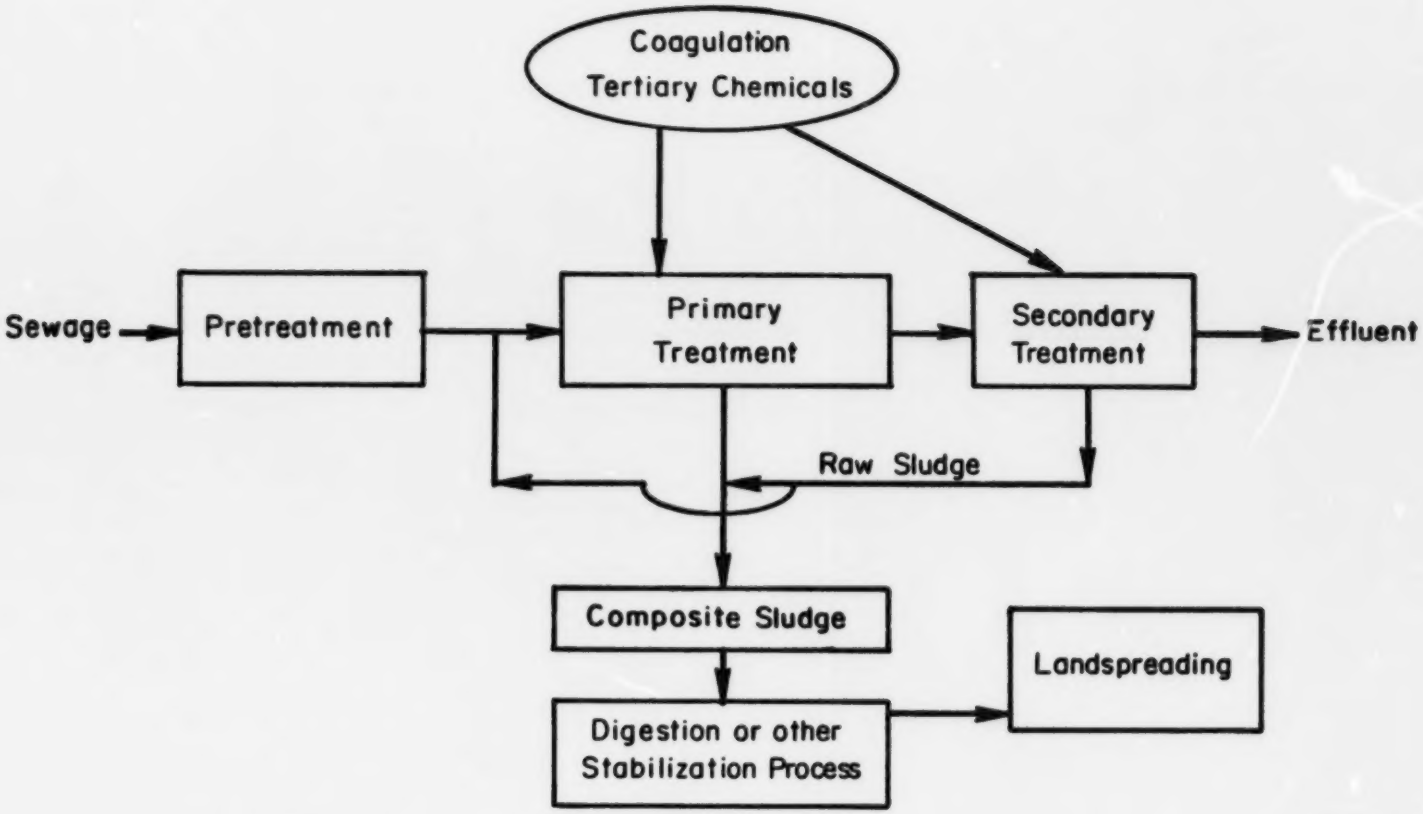


FIGURE 2. SCHEMATIC OF EXISTING SEWAGE TREATMENT PLANTS MODIFIED TO PROVIDE SECONDARY AND/OR TERTIARY TREATMENT

Chemical sludges resulting from high pH lime coagulation (separate tertiary system) are nonvolatile and are considered nonputrescible and essentially bacteria free. The sludge is considered to have some value as a fertilizer due to its phosphate content, which is slowly released. The sludge may have some value as a soil conditioner or for pH control. However, coprecipitated heavy metals content may be high, depending on the wastewater [1, 5, 8].

Primary, secondary, or tertiary sludges can be disposed of separately. However, as depicted in Figure 2, sludges are often in combination. Newer activated sludge plants often do not use a separate presedimentation system. Presently, coagulation chemicals are used for phosphorus removal in conjunction with either primary or secondary treatment.

Because of the bacterial content of unstabilized sludges, putrefaction results when oxygen is consumed and anaerobic decomposition dominates. Anaerobic digestion for 10 (high-rate thermophilic) to 30 (standard-rate mesophyllic) days destroys up to 60 percent of the organic matter. The gas formed in this process (anaerobic digestion) is 55 to 80 percent methane, 30-35 percent carbon dioxide, 2-3 percent hydrogen sulfide, and lesser amounts of nitrogen, carbon monoxide, hydrogen, and other odorous substances. The sludge gas is often utilized to maintain digester temperature in the optimum mesophyllic range of 32-38 C. Sufficient gas is often available to meet the normal energy operation demands of the sewage treatment plant. However, due to seasonal and diurnal variations related to digester insulation integrity and--more important--the variability of sludge characteristics, gas production is variable and not considered a dependable energy source. Thus, the gas is often flared [1, 5, 6, 7].

In addition to the loss of mass due to gas evolution, a portion of the liquid phase of the sludge (supernatant liquor) is often drawn off and recycled to the plant, thus further reducing the volume of the sludge [1, 5, 7]. Some characteristics of digester supernatants are shown in Table 1. Under anaerobic conditions, 80 percent of the phosphates present in the sludge can be expected to be solubilized and thus also be present in the recycled supernatant [9].

The final product in the case of a well digested sludge is a black liquid similar in appearance to a crude oil emulsion and it often evolves a similar odor. A partially digested sludge may produce odors, attract flies, and contain considerable counts of pathogenic organisms and viable seeds. Normal digester operation is semicontinuous, and raw sludge is periodically incorporated with the digester sludge and digested sludge is withdrawn [1, 5, 7].

Since anaerobic digestion is subject to process upset due to a variety of toxic influents, aerobic stabilization (aerobic digestion) is sometimes used. Basically, the process involves aeration of sludge until destruction of a large portion of the organics has occurred. As opposed to anaerobic digestion, the production of a stabilized sludge requires energy for aeration [1, 5, 6, 7].

Table 1. PROPERTIES OF DIGESTER SUPERNATANT [7]
(Municipal Wastewater Sludge)

Item	Standard rate	High rate
Total solids (mg/ℓ)	4,000-5,000	10,000-14,000
Total suspended solids (mg/ℓ)	2,000-3,000	4,000-6,000
BOD (mg/ℓ)	2,000-3,500	6,000-9,000
Volatile solids (mg/ℓ)	650-3,000	2,400-3,800
Alkalinity (MO) (mg/ℓ)	1,000-2,400	1,900-2,700
H_2S (mg/ℓ)	70-90	190-440
NH_3-Nitrogen (mg/ℓ)	240-560	560-620
pH	7.0-7.6	6.4-7.2

Although digester conditions present pathogenic organisms with a hostile environment, the conditions are not lethal. The principal bactericidal effect appears to be related to a natural dieoff with time. Bacterial concentrations in digested primary sludge and undigested waste activated sludge are presented in Table 2. The large differences between raw waste-activated sludges A and B, which were taken 11 days apart, are not unexpected and probably represent day-to-day fluctuations. Consistent differences between aerobic and anaerobic destruction of pathogens have not been reported [7].

Included in Table 3 are selected reports of sludge compositions available in the literature relative to landspreading of liquid sewage sludge. Elements considered as plant macronutrients (N, P, K, Ca, Mg, and S) are presented as percent solids (dry weight basis). The major micronutrients (B, Mo, Fe, Mn, Cu, and Zn) and other elements of potential concern (Cd, Hg, Ni, Pb, Cr, etc.) to sludge landspreading are presented as parts per million. The major fertilizer constituents of sludge (N, P, and K) are usually reported as total nitrogen, P_2O_5, and K_2O, and usually range in value from 2.0-6.0, 2.0-8.0, and 0.2-0.8 percent of dry solids, respectively. Little information relative to the lesser macronutrient (Ca, Mg, and S) concentrations are presented in the published literature.

As discussed earlier, the heavy metals associated with sewage sludges arise from various sources. Industrial discharges are probably responsible for the higher concentrations of reported heavy metals, particularly the values reported for Cd, Ni, Pb, and Cr. Even with strict industrial discharge controls, the reduction of heavy metals--specifically, elements considered as micronutrients, would not be expected to decrease concentrations much below reported mean values [7]. In addition to elements which are contained in foods, high concentrations of micronutrients such as Zn, Cu, and Fe may be considered on a municipal level as non-point source pollutants.

TREATMENT PLANT CONTROL OF PATHOGENS

Of major concern from a human health standpoint when considering landspreading of sludges is the viability of pathogens. Dean and Smith [7] summarize pertinent research in the area of treatment plant pathogen control. Major portions of this discussion are included here.

As an alternative to digestion, sludge may be stabilized by adding lime to a pH near 12 [25]. About one quarter ton of lime is required per ton of sludge solids. Lime treatment provides a high level of bacterial disinfection (Table 4). Viruses are also destroyed by high pH although tuberculosis bacteria and some parasitic eggs may be more resistant. High pH inhibits bacterial growth but does not decompose organic matter. Since most soils and crops are benefited by lime treatment, there should be many agricultural uses for lime stabilized sludges. A limed sludge may putrefy in a lagoon as bacterial action at the edges produces CO_2 and the pH drops. If a limed sludge is dispersed in a well-aerated soil,

Table 2. BACTERIA IN SEWAGE SLUDGE [7]
(per 100 ml)

	Fecal coli ($\times 10^6$)	Salmonella	Pseudomonas
Raw primary	11.4	460	46,000
Trickling filter	11.5	93	110,000
Raw WAS[(a)]	2.8	74	1,100
Raw WAS (thickened) - B	20	9,300	2,000
Raw WAS - C	2.0	2,300	24,000
Anaerobic digested primary	0.39	29	34
Aerobic digested WAS	0.66	150	100,000
Anaerobic digested WAS	0.32	7.3	1,000
Iron primary	32	460	21,000
Lime primary pH 9.0	32	1,500	24,000
Lime primary pH 11.5	0.014	<3.0	<3.0

(a) Waste activated sludge.

TABLE 3. REPRESENTATIVE SLUDGE COMPOSITIONS

City	Date	Comments	pH	T.S./V.S.[a]	Macronutrients[b]						Micronutrients[c]		
					N/NH_3-N	P/P_2O_5	K/K_2O	Ca	Mg	S	B	Mo	
Dayton, O.	-32	imhoff	6.7	4.8/58	3.4/--	--	--	--	--	--	--	--	
--	51-55	Activated (min)	--	--	4.8/--	--/4.0	--	--	--	--	6	6	
--	51-55	Activated (max)	--	--	6.01/--	--/7.4	--	--	--	--	74	45	
--	51-55	Activated (avg)	--	--	5.6/--	--/5.7	--	--	--	--	33	16	
--	51-55	Digested (min)	--	--	1.8/--	--/0.9	--	--	--	--	4	2	
--	51-55	Digested (max)	--	--	3.1/--	--/5.0	--	--	--	--	15	12	
--	51-55	Digested (avg)	--	--	2.4/--	--/2.7	--	--	--	--	9	6	
6 Conn. cities	-53	6 plants (max)	7.9	--	--	--	--	--	--	--	360	--	
6 Conn. cities	-53	6 plants (min)	5.4	--	--	--	--	--	--	--	160	--	
6 Conn. cities	-53	6 plants (avg)	6.1	--	--	--	--	--	--	--	211	--	
--	-53	Digested	--	6.3/--	3.0/--	0.80/--	0.18/--	1.42	0.09	--	12	12	
Jasper, Ind.	-56	Digested	5.8	--/63.1	5.89/--	--/3.49	--	--	--	--	--	--	
Richmond, Ind.	-56	Digested	6.9	--/50.0	2.24/--	--/4.34	--	--	--	--	--	--	
Richmond, Ind.	-56	Activated	6.2	--/68.6	3.02/--	--/3.64	--	--	--	--	--	--	
Jasper, Ind.	-56	Activated	6.8	--/47.5	3.51/--	--/2.81	--	--	--	--	--	--	
Chicago, Ill.	-59	Activated	--	--/62.6	5.60/--	--/6.97	--/0.56	--	--	--	--	--	
Milawaukee, Wisc.	-59	Activated	--	--/72.3	5.96/--	--/3.96	--/0.41	--	--	--	--	--	
Washington, D.C.	-59	Digested	--	--/43.8	2.06/--	--/1.44	--/0.14	--	--	--	--	--	
Rochester, N.Y.	-59	Digested	--	--/47.2	2.54/--	--/1.16	--/0.29	--	--	--	--	--	
San Diego, Calif.	-59	Digested	--	3.44/--	2.73	--/4.78	--/0.83	--	--	--	--	--	
Des Moines, Iowa	-59	Digested (P, A, TF)	--	--/38.6	1.81/--	--/3.31	--/0.40	--	--	--	--	--	
Nottingham, Eng.	-62	Digested (activated)	--	--/43.7	2.59/--	--/2.17	--/0.38	--	--	--	20	--	
Calumet, Ill.	-66	Digested	7.1	2.93/45	4.95/2.06	2.52/--	0.52/--	4.23	0.99	0.23	68	2	54.
Chicago, Ill.	-69	Digested	--	10.6/--	2.4/--	3.1/--	0.40/--	2.35	0.67	--	--	--	28.
Athens, Ga.	-69	Industry and Residential	--	4.8/--	3.65/--	0.378/--	0.186/--	1.58	0.12	--	11	13	
Athens, Ga.	-69	Mostly residential	7.0	7.1/--	2.64/--	0.745/--	0.165/--	1.33	0.07	--	13	11	
New York, New Jersey	-70	17 plants (min)	--	--	--	0.29/--	0.18/--	3.7	0.22	--	11	20	5.
New York, New Jersey	-70	17 plants (max)	--	--	--	2.1/--	2.7/--	0.94	0.86	--	38	91	32.
Hamilton Co., Ohio	71-73	80 samples (average)	--	--	--	--	--	--	--	--	--	--	
Uppsula, Swed.	-72	--	--	--	--	--	--	--	--	--	--	--	
8 Minn., cities	-72	Digested (max)	--	--	--	--	--	--	--	--	86	--	
8 Minn., cities	-72	Digested (min)	--	--	--	--	--	--	--	--	12	--	
Aurora, Cnd.	-73	Large Composite town	--	--	--	--	--	--	--	--	--	--	7.
Thornhill, Cnd.	-73	Residential	--	--	--	--	--	--	--	--	--	--	9.
Ashbridge, Cnd.	-73	Heavy Industrial town	--	--	--	--	--	--	--	--	--	--	16.

(a) T.S. – percent total sludge solids; V.S. – percent volatile total solids.
(b) Macronutrients presented as percent of total solids (dry basis).
(c) Micronutrients presented as parts per million (ppm.) of total solids (dry basis).

TABLE 3. REPRESENTATIVE SLUDGE COMPOSITIONS

Nutrients[b]				Micronutrients[c]												
$/K_2O	Ca	Mg	S	B	Mo	Fe	Mn	Cu	Zn	Cd	Hg	Ni	Pb	Cr	Other	(Ref.)
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(10)
--	--	--	--	6	6	--	65	385	950	--	--	--	--	--	--	(11)
--	-	--	--	74	45	--	190	1,500	3,650	--	--	--	--	--	--	(11)
--	--	--	--	33	16	--	134	916	2,500	--	--	--	--	--	--	(11)
--	--	--	--	4	2	--	30	315	1,350	--	--	--	--	--	--	(11)
--	--	--	--	15	12	--	790	1,980	3,700	--	--	--	--	--	--	(11)
--	--	--	--	9	6	--	262	643	2,459	--	--	--	--	--	--	(11)
--	--	--	--	360	--	--	280	1,025	3,570	--	--	--	--	--	--	(12)
--	--	--	--	160	--	--	105	465	2,200	--	--	--	--	--	--	(12)
--	--	--	--	211	--	--	172	758	3,205	--	--	--	--	--	--	(12)
8/--	1.42	0.09	--	12	12	--	177	453	2,415	--	--	25	--	--	95-Ba, 20-Na	(13)
--	--	--	--	--	--	—	--	--	--	--	--	--	--	--	--	(2)
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	22.9%-C	(2)
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	26%-C	(2)
--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	44%-C	(2)
/0.56	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(14)
-/0.41	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(14)
-/0.14	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(14)
-/0.29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(14)
/0.83	--	--	--	--	--	--	--	--	--	--	--	--	--	--	10,700-Na	(15)
/0.40	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	(16)
-/0.38	--	--	--	20	--	--	410	62	120	--	--	10	--	--	6.0-Co	(17)
.52/--	4.23	0.99	0.22	68	2	54,539	4,881	819	3,106	34	--	68	3,072	1,672	7,747-Al, 1.7%-Cl, 4,061-Na	(18)
.40/--	2.35	0.07	--	--	--	28,900	200	2,500	8,600		--	300	800	3,000	23%-C	(19)
.186/--	1.58	0.12	--	11	13	--	229	520	2,825	--	--	26	--	--	63-Ba, 340-Na	(20)
.165/--	1.33	0.07	--	13	11	--	148	415	2,180	--	--	25	--	--	114-Ba, 240-Na	(20)
.18/--	3.7	0.22	--	11	20	5,400	78	380	690	--	--	44	50	200	2.0-Na, 4.5-Al, 1.2-Ti%	(24)
.7/--	0.94	0.86	--	38	91	32,000	400	1,900	2,900	--	--	900	1,200	8,100	0.25-Na, 1.0-Al, 17-Ti%	(24)
--	--	--	--	--	--	--	--	1,840	6,380	93	3.2	733	2,400	--	--	(7)
--	--	--	--	--	--	--	373	1,960	4,890	11	12	88	293	176	12.2-Co, 6.6-As, 7.3-Se	(21)
--	--	--	--	86	--	—	882	1,550	2,390	369	--	321	3,990	1,010	--	(22)
--	--	--	--	12	--	--	151	264	594	6	--	6	147	12	--	(22)
--	--	--	--	--	--	7,000	260	30	9,400	10	--	120	235	16,000	--	(23)
--	--	--	--	--	--	9,000	450	2,400	1,100	5	--	25	185	6	--	(23)
--	—	--	--	--	--	15,000	280	1,100	5,800	45	--	170	1,425	4,300	--	(23)

Table 4. BACTERIOLOGICAL STUDIES OF SLUDGE PRODUCED IN PLANT-SCALE TESTS OF LIME STABILIZATION TO pH 11.5 [7]

Sludge	Bacterial count (organisms/liter of sludge)		
	Salmonella species	Pseudomonas aeruginosa	Total aerobic count x 10^{-8}
Alum-primary	110	1,300	41
Limed alum-primary	None detected	None detected	5.0
Ferric-primary	>24,000	610	190
Limed ferric-primary	None detected	None detected	0.29

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aerobic organisms will consume the organic matter and no putrescent odors should be produced.

Pasteurization is being used in Germany and Switzerland for digested sludge that is to be spread on pastures during the grazing season. Generally, 25 to 30 minutes heating at 70 C is suggested for destruction of cysts, oocytes, pathogens, worm eggs,and viruses [26]. Direct steam injection is used because organic fouling and inorganic scaling on direct heat exchanger surfaces reduce the effective heat transfer. Recovery of heat from pasteurized sludge by means of vapor heat exchangers can be used, but it requires a substantial capital investment. Small plants cannot economically recover the heat of pasteurization. The sludge should be cooled enough to avoid killing vegetation before it is applied to the land.

Direct steam injection, which raises the temperature above 75 C for 1 hour, is an effective way to destroy pathogens and reduce coliform indicators below 1000 counts per 100 ml [27]. Warm sludge can be applied to growing grasses if the temperature at the soil surface does not exceed 60 C. Because evaporative cooling of sprayed sludge can reduce the temperature significantly, and heat may be lost in transit from plant to spreading site, direct cooling may not be necessary in most cases. Adverse effects are not expected if hot sludge is applied to bare soil before crops are started.

The cost of sludge pasteurization was calculated by Treibel in 1967 for German conditions [26]. The heat for pasteurization was derived from the methane gas produced by the anaerobic digestion and heating costs were not included. The cost of fuel to heat sludge from 15 to 75 C was estimated at about $4.50 per metric ton (ton) of dry sludge [27]. Because of shortages and rising costs, the fuel cost to heat sludge from 15 to 75 C has risen to about $20 per ton of dry sludge [28]. On a solids basis, a cost of between $11 to $22 per ton of dry solids is a fair preliminary estimate.

Heat treatment of sludge to improve dewaterability is carried out at temperatures above 160 C for about half an hour. These conditions will completely destroy all living organisms. If oxygen is present, some organic matter may be oxidized. The process is then called wet oxidation. All heat treatment processes increase the concentration of soluble organic matter and ammonia in the supernatant liquor or "soup". This soup, although sterile when it is produced, is a rich nutrient broth that can putrefy if it is allowed to come into contact with bacteria that are in the air or on container walls. The dewatered sludge is, however, resistant to putrefaction [29].

Lagoon or other storage for many months is frequently depended upon to reduce the numbers of pathogenic organisms, particularly those that cannot multiply outside the human body [30, 31]. Storage may be necessary in any case if sludge is disposed of only part of the year, and additional storage lagoons can be built into the system to provide more protection against transmission of disease.

SECTION VI

SLUDGE HANDLING AND DISTRIBUTION SYSTEMS

The technical feasibility of landspreading depends on many factors which can vary significantly from one operation to another. However, the major consideration from the operator's standpoint relates to the economics of the operation. In many cases, due to lack of concise economic data, the decision to utilize landspreading is intuitive. However, many operators do perceive the specific importance of (1) providing ample retention volume(s) to allow for operational irregularities and (2) selecting the proper sludge conveyance mode(s) and application method(s) which optimize the individual landspreading system.

RETENTION PROVISIONS

Many sewage treatment plants which utilize landspreading do not have separate retention provisions for containing the sludge prior to landspreading. For instance, many plants which employ anaerobic digestion utilize portions of the digester volume for storage. Where possible, a secondary unheated digester may provide the required storage capacity. In anticipation of periods when sludge cannot be applied to the land, digester withdrawals proceed at an accelerated rate to ensure the availability of retention volume until the landspreading operation can be resumed. The fact that digesters often serve as retention vessels can lead to potential problems at the landspreading site if the sludge withdrawn for landspreading is insufficiently stabilized and contains high counts of pathogenic microorganisms.

Some sewage treatment plants operate sludge lagoons for either routine sludge dewatering or as holding reservoirs when landspreading practices are temporarily interrupted due to adverse weather conditions and/or unanticipated equipment failure. By contrast, 9-meter-deep intermediate "retention reservoirs" have been expressly designed into the landspreading operation conducted by Chicago's METRO at their Fulton County strip mine reclamation site. Other plant appurtenances such as the sludge wells associated with decommissioned or seasonally

operated vacuum filter dewatering equipment are often utilized to provide retention volume. In a rare case, even a cell of a secondary aerated system may be utilized for the retention of liquid sludges prior to transporting the sludge to the landspreading site.

Extended use of vented sludge wells as holding reservoirs allows time for additional stabilization. However, open retention vessels may create odors if the sludges have not been sufficiently stabilized. Some plant operators have had difficulty in resuspending sludges which have been retained in lagoons, wells, and secondary unheated digesters due to long-term gravity separation of the solid and liquid phases of the sludge.

CONVEYANCE MODE AND APPLICATION METHODS

Tank trucks are most commonly used to convey sewage sludges from small treatment plants. The major attribute of this sludge haulage mode is its flexibility. Pipelines are also utilized to transport sludges over both very short and long distances. Basic to the decision of committing the required capital expenditure for a sludge pipeline is the "useful life" of the disposal site and the assurance of land availability in close proximity to the disposal site. These requirements necessitate ownership of sufficient land and public acceptance of the landspreading operation. Rail tank cars and barges are also being employed to convey sewage sludges. The city of Chicago has utilized rail tank cars and is presently conducting the largest and most extensively engineered sludge landspreading operation to date involving the use of both barge and pipeline transportation modes.

Application methods such as sub-sod injection (first applications up to 360 dry tons per hectare per year) and spray irrigation are being used by Chicago METRO at their Fulton County stripmine reclamation site. However, most smaller sewage treatment plants that utilize landspreading discharge sludge directly to the land from tank trucks. Tank truck associated ridge and furrow and spray irrigation application procedures are also conducted, particularly when the site is under cultivation. Irrespective of application method and land use, liquid sludges are often incorporated into the soil by plowing and discing.

Tank Trucks

The tank trucks utilized for transporting liquid sewage sludges range in carrying capacity from about 2.3 to 28.4 m^3. The smaller capacity trucks (2.3-13.2 m^3) are usually straight tank trucks, while the larger are tractor-trailer rigs. The trucks, either gasoline or

diesel fueled, seldom average more than 1.3 or 1.7 kilometers to the liter. A straight tank truck designed for hauling and spreading sludge can be purchased either as a single unit built to specifications, or the chassis, only, may be purchased for later tank installation. Vehicles of this type can have a "useful life" exceeding 10 years. A wide range of tank truck configurations is possible. Some communities have converted water tanks and installed them on a truck chassis or even have carried them in a conventional dump truck, thus allowing dual use of the truck. A few communities have converted gasoline trucks, and one has even baffled and enclosed the box of a large dump truck in order to transport liquid sewage sludge. Most of the tank trucks utilize gravity filling and emptying methods. Some trucks, however, are equipped with gasoline motor driven pumps for loading and spreading. The pumps can often supply the head of pressure required for short range spray irrigation. Keeping these sludge pumps primed can be a problem and constitute an additional energy requirement. As a general rule, tank trucks also include in-cab sludge release controls.

Tank trucks used for sludge disposal are usually equipped with devices to increase the area of discharge. The discharge system often consists of a central supplied manifold (>10 cm I.D. input orifice) which is split into two lateral manifolds with about six to ten output orifices (>5 cm I.D.). The width of sludge spread in this design is usually 2.5 to 3 meters). The amount applied depends primarily on the truck speed, tank volume, and differential discharge control (if any). With this design, it is possible for the tank truck operator to produce a uniform spread over the truck run. Other sludge spreader designs include single open-close orifices and single orifices equipped with splash pans. However, in these cases, the sludge pattern is considerably less than the width of the truck, and the resulting pattern impedes uniform incorporation into the soil.

Tank truck haul schedules are controlled primarily by the crops and by soil moisture. Once a crop such as corn has germinated, landspreading from a tank truck can only reasonably be continued as a gravity ridge and furrow or a spray irrigation procedure. Application in grassed fields (pasture and grazing land) does not appear to be constrained. With exception of some well-packed sandy soils, as soil moisture increases so do the chances that the tank truck may become "bogged down". This is a problem in clay soils. Therefore, in order to extend the time that trucks can operate, high flotation tires are often used. This practice also somewhat alleviates soil compaction problems due to heavy wheel loadings. Many landspreading operations in the North also take full advantage of frozen ground conditions and continue landspreading of liquid sludge through the winter months.

Pipeline

In some cases sludges are transported via pipeline from separate sewage treatment plants for processing at a common collection point. Chicago METRO utilizes a pipeline to transport sludges withdrawn from barges 11 miles to intermediate land reclamation holding reservoirs. The present use of sludge pipelines by small sewage treatment plants is usually restricted to distances less than 2 kilometers and in most cases is directly associated with field application methods such as ridge and furrow, spray irrigation, flooding, etc. Due to increasing problems of municipal solid waste disposal (including all sludges) and since costs associated with pipeline transport are quite sensitive to economy of scale, research attention will continue to focus on aspects which relate to regional waste transport systems [32].

Design and operation of sludge pipelines can be difficult. In some cases pipelines which experience prolonged freeze periods are both insulated and heated. Sludges can be reasonably transported up to a solids content of 10 percent; however, Raynes [33] suggests that the optimum solids content is nearer 5 percent assuming turbulent flow. When sludge pumping is intermittent, damage due to gas production and blockage due to separation of solids can be avoided by purging the system.

Sparr [34] conducted a significant review of the technical literature relative to design and operation of sludge pipelines and concludes that (1) the head loss caused by the friction of a pipeline conveying sludge varies directly with the viscosity of the sludge flowing within it; (2) increasing the velocity of sludge flow within the pipe in laminar flow decreases the apparent viscosity; (3) increasing the velocity of sludge flow within the pipe in turbulent flow further decreases the apparent viscosity of sludge until the true viscosity of sludge is approached as a limit; (4) reducing the size of coarse sludge particles reduces the viscosity of the sludge; (5) effective grit removal is necessary for economical pumping of sludge in a pipeline; (6) the low velocities experienced in the laminar flow zone when raw primary sludge is pumped often result in deposition of grease on the inner periphery of the pipe wall; (7) pumping anaerobically digested sludge results in lower head loss as a result of friction than pumping raw primary sludge of the same solids content (dry basis) and flow condition; (8) flow velocities in the turbulent flow region tend to prevent deposition of grease within the pipe; (9) maintaining the operating velocity in the lower portion of the turbulent flow zone results in maximum economy for pumping sludge through a long pipeline; (10) little or no grease deposition within the pipeline has been observed over periods of many years when low-

solids-content activated sludge is pumped; (11) pipeline materials and linings influence pipeline head losses as a result of differing friction factors; (12) some pipeline materials and linings such as glass lining, cement lining, and fiber-glass-reinforced epoxy pipe resist the adherence of greases more readily than other materials such as cast iron and steel.

SELECTION OF CONVEYANCE MODE

In determining which transportation mode (pipeline or tank truck) will be selected to convey sludges from the plant to the site, sludge characteristics, elevation differences, distance, and sludge volumes must be considered. The sludge solids concentration is a prime factor. Given a sludge concentration, there is an optimum associated pumping velocity. Other characteristics such as high specific gravity, low temperature, presence of large solid tramp material, and scaling tendency can adversely influence disposal by pipeline more than trucking. Large differences in elevation between the sewage plant and the disposal site increase both capital and operating costs for pipelines and trucking, but pipeline costs would probably be influenced to a greater extent [35].

Long distances between the disposal site and treatment plant tend to favor pipelines. Conversely, shorter distance hauls favor the use of tank trucks rather than pipelines. Chicago METRO is considering transporting sludge (275 kilometers) to marginal farmland by pipeline. Riddel and Cormack [36] conclude that trucks provide the most economical means of sludge transport (digested sludge, 3.5 percent solids) for distances less than 240 kilometers from populations smaller than 10,000. Rail transport may become competitive for greater distances. For 40-kilometer hauls, pipelines are economical for areas with populations greater than 60,000.

Small sludge volumes tend to favor trucking as the mode of transportation. Cities with populations greater than 1.5 million can pump sludges continuously [35]. A study by Bechtel Corporation [37] concludes that pipelines are the most economical form of transport for regional systems involving more than five tons per day of digested sludge (dry basis). Smaller volumes can also be transported by pipeline more economically than by truck; however, the inabilility of the sewage treatment plant to continue a site-specific landspreading operation over a long period of time may rule out the pipeline transport alternative.

SECTION VII

ECONOMICS OF LANDSPREADING

The processing and ultimate disposal of sludge at a treatment plant represents a significant amount of the total expenditures for sewage treatment. As more investigators consider the alternatives available for the ultimate disposal of wastewater treatment sludges, landspreading in the liquid state emerges as an apparently economical means of final disposal. While landspreading in the dewatered and dried state has been a somewhat common practice in the United States for solids disposal and soil improvement, it requires expensive, time-consuming and often troublesome dewatering operations. Landspreading of the liquid sludges, however, eliminates these troublesome aspects, and hence is receiving renewed attention as a means of economical solids disposal rather than simply for land and soil improvement.

TREATMENT PLANT CONSIDERATIONS

Literally thousands of tons of sewage sludge are produced daily in the towns and cities of the United States; and the amounts produced are increasing along with the population. Also contributing to the growing volumes of sludge is the application of secondary biological treatment and chemical treatment methods. Conservative estimates now place the generation of sewage sludge by U. S. municipal sewage treatment facilities, alone, at about 8.2 million tons per year [38] . As these volumes increase, so will the problems and cost of sludge disposal. Therefore, the success and efficiency of a treatment plant, in large part, may be measured in terms of its ability to provide for ultimate disposal of sludge.

The fact that 25-50 percent of sewage treatment plant capital and operating costs are attributable to sludge handling and disposal attests to the magnitude of this problem. The processing and disposal of sludge at a treatment plant thus represent a significant amount of the total expenditure for sewage treatment. Dean and Smith [7] report that the cost of sludge treatment and disposal is a function of the tons of water associated with each ton of solids and that the cost of dewatering and drying liquid sludge can run as much as $55 per ton of solids produced.

Burd [39] has reviewed the significant economic data, and points out that the costs are dependent on plant location and operation factors which in turn are largely affected by climate, physical environment, population, esthetics, system complexity and efficiency, and the characteristics of the wastewater. Unfortunately, there is a scarcity of complete operating records concerning the costs of land disposal systems currently in use relative to the size of the plant. Burd's general review of available economic data, however, yielded average costs for ultimate sludge disposal. These are presented in Table 5.

Table 5. AVERAGE COSTS FOR ULTIMATE SLUDGE DISPOSAL (1966) [39]
(presented in English units)

System	Capital and operating costs, $/dry short ton	
	Average	Range
A. Composting [a]	Not accurately known	
B. Heat drying [a]	50	40-55
C. Incineration		
(1) Wet combustion	42	-
(2) Multiple hearth and fluidized bed	30	10-50
D. Landfilling dewatered sludge	25	10-50
E. Disposal as a soil conditioner w/o heat drying [a] (dewatered)	25	10-50
F. Disposal on land as a liquid soil conditioner [a]	15	8-50
G. Lagooning	12	6-25
H. Barging to sea	12	5-25
I. Underground disposal	Unknown, potentially inexpensive	
J. Pipline to sea	11	-

[a] Gross cost does not account for money received from sale of sludge.

These data indicate that the cost for land disposal of nondewatered sludges is not much greater than lagooning or ocean disposal.

Ewing and Dick [16] have also reviewed the costs of land disposal systems. They state that for a particular plant the costs are a function of sludge characteristics, type of disposal system, population served, land costs, and distance to the disposal area. They further indicate that few actual operating records are available relative to the cost of land disposal. However, they do report some data on the effect of population on sludge disposal costs and some estimated

costs of land disposal compared with the costs of other alternative means for disposal. These data are presented in Tables 6 and 7, respectively. From these data it can be seen that landspreading of liquid sludge does offer an economical means for sludge disposal.

Attempts to collect operating cost data by visiting active landspreading operations were made as part of this research program. For the most part, these attempts confirm the lack of readily available, complete, and reliable cost accounting regarding the landspreading operations. At best, these data (presented in a later section of this report) reflect a wide variation of operating costs, ranging from a low of $2.57 per dry ton to a high of $149 per dry ton.

Table 6. EFFECT OF POPULATION ON UNIT COST OF SLUDGE DISPOSAL (1970) (presented in English units)

Population, millions	Cost of incineration, $/dry short ton	Cost of land disposal, $/dry short ton
0.125	67	30
0.25	57	17
0.5	49	11
1	42	8
2	35	5
4	30	4

AGRICULTURAL CONSIDERATIONS

The literature is replete with examples of the benefits to be derived from landspreading of liquid sludges. Most significant among these benefits are those that relate to the growth-promoting ingredients contained in the digested sludge, specifically, nitrogen, phosphorus, potassium, and certain trace elements. Essentially, the solids portion of the sludge (approximately 3-6 percent) contains most of the nitrogen and phosphorous, while the liquid portion (approximately 94-97 percent) contains most of the potassium. Therefore, to retain the complete fertilizer content and thus realize the greatest benefit from sludge, it must be applied in the liquid form. Also, when applied in the liquid form, the sludge provides a source of supplemental irrigation water.

In addition to providing certain fertilizer requirements as mentioned above, digested sludge can offer a number of other plant-and-crop-growth-promoting features, such as

Table 7. COMPARATIVE COSTS OF SLUDGE DISPOSAL (1970) (presented in English units) [16]

Method	Estimated cost, $/dry short ton
Incineration	50
Wet-air oxidation	42-50
Multiple-hearth	30-57
Fluidized-bed	30
Drying: fertilizer sale	45
Lagooning	
Pumping	7-49
Trucking 5% sludge	18
Trucking 10% sludge	12
Disposal at sea	
Pumping	11
Barging 5% sludge	12
Barging 10% sludge	9
Land application	
Landfill	25
Heat-dried sludge	50
Dewatered sludge	25
Liquid sludge	15
Strip-mine reclamation	16

- Increased humus content of the soil
- Increased soil fertility
- Increased water holding capacity of the soil
- Improved soil structure.

The majority of the information available on the fertilizer and soil conditioning value of liquid sludge is qualitative in nature and states essentially that additions of liquid sludge result in increased plant growth. Little quantitative data can be found. Furthermore, what data are available are not easily compared due to the incomplete nature of the data and due to differences in the sludge characteristics, soil conditions, experimental design parameters, and local environmental conditions.

It is generally agreed that liquid sludge is an economical fertilizer and soil conditioner for the farmer, especially when a municipality furnishes the sludge free of charge and then also pays the cost of transporting and applying the sludge to the farmer's field. However, it is believed that farmers would not be willing to purchase and/or apply the large quantities of sludge required to obtain a crop response comparable to that produced by a much lesser quantity of commercial inorganic fertilizer. For example, studies conducted by Larson, et al [22] are indicative of the amounts of sludge required to produce crop yields equivalent to those produced by commercial fertilizers. On sandy Minnesota soils, a 168 ton per hectare application of sewage sludge was required to produce a corn yield about equal to that obtained with 1.12 ton per hectare of a 20-10-10 fertilizer. When comparing the growth of barley on replicate plots fertilized with liquid sludge and commercial ammonium phosphate (16-20), Merz [15] found that best growth was obtained with ammonium phosphate applied at a rate of 448 kilograms per hectare. Although sludge loading rates of 56 to 112 tons per hectare resulted in improved plant growth, a loading rate of 224 tons per hectare was required to produce a growth equal to that obtained with the ammonium phosphate.

In a recent article, Sabey, et al [40], stated that--disregarding the soil conditioning properties of liquid sludge--land application of sewage sludge for its fertilizer value is not economical when compared with commercial inorganic fertilizers. Evans [41] suggests that liquid sludge cannot compete with commerical fertilizers, since (a) not enough sludge is produced to meet all fertilizer needs and (b) commercial fertilizers are relatively cheap and sludge can become expensive if long transportation distances are involved.

While liquid sludge contains the major and minor nutrients required for plant growth, it is not necessarily a balanced fertilizer for many crops and soils. The sludge composition will vary depending on the wastewater composition and the sewage treatment and sludge

stabilization processes. Normally, the sludge is low in potassium, medium in available nitrogen, and high in phosphorus. Nevertheless, under the conditions mentioned above (i.e., delivered and applied on fields at no cost to the farmer), liquid sludge can be an economical and satisfactory fertilizer supplement and soil conditioner. Through the addition of organic matter, sludge amended soils have been shown to improve markedly with regard to fertility, water holding capability, humus content, and tilth. Thus, the soil conditioning properties of sludge are perhaps more important than its fertilizer content. This attribute of sludge makes it an effective agent for use in soil maintenance programs or in the reclamation of marginal lands which have been depleted of organic matters through misuse. Here again, however, little comparable data are available to adequately quantify the value of sludge.

SECTION VIII

SLUDGE-SOIL-PLANT INTERACTIONS

One of the major factors in land spreading of liquid sludge is the land itself, especially the upper horizons of the soil in which plants grow. A well engineered landspreading operation must recognize the limitations of the soil and then design for the maximum utilization of the assimilative capacity of a soil such as its filtration, biological degradation and absorption properties. The ultimate benefit derived from the purifying and assimilating capacity of soil is the establishment of favorable plant cover. This inevitably depends on the three closely related factors--the triad of liquid sludge properties, land and soil properties, and plant nutrient requirements.

The sludge properties have been covered already in an earlier section of this report. This section will discuss the general physical, mineralogical, and chemical characteristics of the soil, physiographic considerations, physical characteristics of liquid sludge-soil interaction, and chemical characteristics of liquid sludge-soil-plant interactions.

PHYSICAL CHARACTERISTICS

Physical characteristics such as grain size, bulk density, and porosity--together with past performance experience--are helpful in predicting soil permeability. The sizes of soil particles, which range from fine gravel to clay, determine its texture. The texture of the soil influences the flow and retention of soil water, the circulation of air, and the rate of chemical reactions within the soil. The structure of the soil is determined by the grouping or arrangement of the soil grains or formation of soil granules, blocks, or plates in loamy or finer textured soils, as opposed to coarse-textured soils where each soil particle seems to function separately. Favorable structure in fine textured soils is essential to the satisfactory movement of water and air and plant root penetration. It also provides for adequate food supply.

Bulk density is influenced by structure, texture, and compactness. It is directly related to the porosity of the soil, for the reduction of the space between soil particles reduces the volumes of pore spaces and hence, the capacity of the soil to allow free movement of air, water, and plant roots.

The rate at which water percolates into the soil (or rate of infiltration) is influenced by soil properties and hydraulic slope. Water standing on gravelly or coarse sandy soils percolates into the soil rapidly. On fine-textured clay soils, water may collect and stand on soils with little infiltration. Furthermore, infiltration rate is usually higher at the beginning of a rain or irrigation than it is several hours later [42].

Permeability is the measure of flow in any direction and is influenced by the moisture content of the soil, the physical properties of the soil such as size and shape of pore spaces, and the specific weight and viscosity of the soil water.

MINERALOGICAL CHARACTERISTICS

Quartz commonly dominates sand and silt fractions of the soil. Also found in these fractions are feldspars, micas, gibbsite, hematite, etc. The clay fraction also contains some of these minerals, but the more important group is that of the layer silicates. A typical example is montmorillonite. It possesses a high cation exchange capacity which is caused by (a) isomorphous substitution and (b) ionization of hydroxyl groups attached to silicon of broken tetrahedron planes. The negative charges created in the former are distributed more uniformly on interlayer surfaces, whereas the latter are at corners and on edges. Water and polar organic molecules, such as glycols, polyglycols, polyglycol ethers, and some proteins can be sorbed in the interspaces of the layer silicates to cause swelling [43].

Also important in the mineral characterization of clay fraction or whole soil are the hydrated complexes of iron, aluminum, and manganese. The cation exchange capacity of the clay soil is decreased by the formation of these positive charge nonreplaceable hydroxy cation interlayers.

CHEMICAL CHARACTERISTICS

Sand and silt, which are dominantly quartz, are generally quite inactive chemically. The most active part of soil is the colloidal fraction, namely clay and humus. These two fractions are the common sites of soil chemistry (ion exchange and physical adsorption) and soil microbiology.

Soil microbiology is important in humus formation. As organic tissue is incorporated into a moist warm soil, it is immediately attacked by a host of different soil organisms. The easily decomposed compounds quickly succumb, yielding simple soluble products, while the resistant materials are only modified from the original plant and animal tissues. Also present in the amorphous, colloidal humus fraction are compounds synthesized within microbial tissues which remain as the organisms die.

The colloidal fractions of humus are made up of carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus rather than silicon, oxygen, aluminum, and iron, as in case of clay. The negative charges arise from exposed -COOH and -OH groups from which the hydrogen may be replaced by cation exchange. The cation exchange capacity of humus far exceeds that of clay.

PHYSIOGRAPHIC CONSIDERATIONS

The physiographic characteristics of the land are extremely important considerations in landspreading, as they can either aggravate or ameliorate the potential for ground and/or surface water contamination. While the potential for groundwater contamination exists, it does not appear to be a serious hazard if sludges are applied properly. Concern for contamination of surface waters via runoff from sludge amended soils, however, is valid. Several factors must be considered in an assessment of potential contamination of surface waters via localized runoff from the sludge spreading site. The most significant of these factors are the slope of the land, the soil permeability, the distance to the water course, and vegetative cover.

Generally speaking, the land should be level enough to minimize surface water runoff. Troemper [44] noted that when applying sludge to an area of land by flooding, sludges with a reasonably high solids concentration (5 to 6 percent) would run readily down a gentle slope. The Interdepartmental Committee on Sludge Disposal, Toronto, Ontario, Canada [45], has suggested interim guidelines for the disposal of sewage sludge on northern and southern Ontario agricultural lands. These interim guidelines relate the maximum sustained slope to the minimum distance to the water course and are shown in Table 8.

Table 8. MAXIMUM SUSTAINED SLOPE VS. MINIMUM DISTANCE TO WATERCOURSES [45]
(presented in English units)

Maximum sustained slope	Minimum distance to watercourse	
	For sludge application during May to Nov., inclusive	For sludge application during Dec. to Apr., inclusive
0 to 3%	200 ft.	600 ft.
3 to 6%	400 ft.	600 ft.
6 to 9%	600 ft.	No sludge to be applied
Greater than 9%	No sludge to be applied unless special conditions exist	No sludge to be applied

Some optimum characteristics and management procedures for land to be used for the disposal of sewage sludge were suggested by Bell [35]. These characteristics are for land which would receive heavy sludge applications (i.e., approaching the limits of vegetative cover to remove the nutrients contained in the sludge) under Ontario, Canada, climatic conditions. Bell suggests that, if the slope of the land is greater than 3 percent, the soil should be reasonably permeable to enhance absorption of surface water and thereby inhibit runoff. A permeability coefficient of at least 10^{-5} cm/sec was suggested and it was indicated that soils possessing coefficients of a least 10^{-4} cm/sec would exhibit good drainage quality. Flach [46] indicates that the degree of soil limitations are slight when the soil permeability is within a range of 4.2×10^{-4} to 4.2×10^{-3} cm/sec. Soil limitations are considered severe when permeabilities are less than 1.4×10^{-4} cm/sec or greater than 1.4×10^{-2} cm/sec.

To reduce the potential of contaminating surface waters with runoff or with percolating groundwater, the sludge disposal site should be sufficiently remote from surface water courses. However, to recommend a single minimum distance from a water course which would be valid for all sludge spreading sites would not be practical. The required distance is based upon the peculiarities of individual sites.

The selection of vegetative cover can also influence the potential for contamination of surface waters, as certain plants are superior to others from the viewpoint of stabilizing the soils and controlling erosion and surface water runoff. For example, most grasses would be superior to crops such as soybeans or corn in the control of runoff. However, this aspect would have to be weighed against the plant characteristics relative to nutrient uptake and amenability to fertilization with liquid sludge. Those harvested plants which are capable of efficiently removing the nutrients contained in sludge would be valuable in reducing the possibility of nutrients accumulating

to the extent that they could pollute surface and groundwater or cause soil toxicity problems.

PHYSICAL CHARACTERISTICS OF LIQUID SEWAGE SLUDGE-SOIL INTERACTION

When liquid sludge is spread on the land, two soil improvement practices are simultaneously being accomplished, irrigation and fertilization. The dual benefits are possible because the liquid sludge is made up of both liquid and solid phases with each phase containing plant nutrients. The quality of the sludge can have direct effect on the physical properties of the soils upon which it is deposited.

Soil structure and texture, depth of liquid sludge on soil surface, temperature of liquid sludge and soil, and moisture content of soil may influence the intake of the water phase of the sludge. Usually, lower infiltration rates are experienced with fine-textured soil than with coarse-textured soil. When enough sludge is applied, sealing of the soil surface with sludge solids takes place regardless of the soil texture. The infiltration capacity of the soil is restored by drying of the sludge.

Because of the low plasticity and cohesion of the sludge humus, liquid sludge may alleviate the unfavorable structural characteristics caused by a high proportion of clay. It imparts to sandy soils some chemical reaction sites for nutrient exchanges and promotes soil aggregation. For example, digested sludge applied on a sandy soil and Cheshire loam soil at the rate of about 67 tons per hectare increased field moisture capacity, noncapillary porosity, and cation exchange capacity from 3 to 23 percent, organic matter content from 35 to 40 percent, total nitrogen up to 70 percent, and soil aggregation from 25 to 600 percent [12]. It was observed that greater benefits occur in sandy soil than in loams.

Another physical characteristic of liquid sludge-soil interaction is the rate of dewatering of the sludge. This is influenced by both the soil properties and climate or weather conditions, such as the intake rate and infiltration rate of the soil and the rate of sludge drying caused by convective and radiative heat transfer [47,48]. The weather factors controlling the evaporation rate of free water from soil surfaces are the amount of rainfall, the humidity, air velocity, and temperature. It has been reported that by varying temperatures, humidity differences, and flow rates of air over a broad range of values when sludge temperatures were low and the air humidity was high, the rate at which digested sludge dried by convective heat transfer was only about one-half the rate of evaporation from a free water surface. However, when sludge temperatures were high and air humidity was low, the rate of convective drying of digested sludge approached the rate of evaporation from a free water surface.

An investigation of the factors determining the dewatering rate of digested sludge on soils showed that, when sludge is first applied on soils, dewatering of the sludge is fairly constant and the rate depends on filtration of water into soils and water lost evaporation. When the water content of sludge has been reduced to about 80 percent by weight, further drying of the sludge is by evaporation alone. [30]

The rate of infiltration of sludge liquid depends on the initial soil moisture content and solids content of the sludge. The higher the soil moisture and sludge solids contents, the lower is the rate of infiltration.

Thomas and Law [49] have reviewed the use of the soil as a wastewater treatment method and report that many wastewater treatment systems have been plagued with the problem of physical clogging of the soil and subsequent loss in infiltration rate. Under heavy sludge application rates, similar clogging problems might be encountered. Generally, Thomas and Law suggest that soil clogging is related to the frequency and rates of application and that clogging has not been noticed with frequencies which permit the soil to dry between applications.

McGauhey and Krone [50] have also looked at the problem of soil clogging in somewhat greater detail. Their conclusions, which appear to relate to landspreading of liquid sewage sludge, were that the principal mechanism of soil clogging is due to physical phenomena, but that biological and chemical factors may also play a role in soil clogging. The primary physical factors involved were reported to be compaction from loads imposed on the soil surface from landspreading equipment, or from "smearing" of the soil surface by treatment of the site following landspreading, i.e., plowing and discing associated with agricultural activities at the site. They also suggest that the interparticle spacing of larger, lower grains of the soil may become blocked by migration of fine grains of soil from the upper zone.

The biological aspects of soil clogging were indicated to be related to anaerobic conditions which would develop under conditions of frequent, heavy applications of wastewater. Causes cited here were that (a) organic slimes were created by anaerobic bacteria which could clog the soil, (b) fine particles of precipitated ferrous sulfide resulting from anaerobic degradation of sulfides could create a layer on the surface which inhibits infiltration, and (c) anaerobic conditions could permit the accumulation of lignins, waxes, tannins, cutins, and fats which are resistant to degradation by anaerobic bacteria.
As mentioned earlier, soil clogging problems relative to the landspreading of liquid sewage sludge should not be an extremely great problem except under conditions of prolonged, frequent, heavy applications of liquid sludge. Generally speaking, these conditions would tend to be the exception rather than the rule as most landspreading activities are conducted by plants in the 3.8-19 x 10^3 m^3/day (1-5 mgd) size class. Normally, these plants appear to have sufficient

amount of land area available to enable the sludge applications to be rotated from site to site, thereby providing adequate time for the various sites to recover and maintain the aerobic conditions necessary to prevent soil clogging.

CHEMICAL CHARACTERISTICS OF LIQUID SLUDGE-SOIL-PLANT INTERACTIONS

About 90 to 99 percent of the sludge is water, and the remaining solids normally range in organic content from 50 to 70 percent. The addition of water to cropland as supplemental irrigation in dryer climates or during prolonged precipitation free periods in other regions is certainly conducive to plant growth. Assuming that 90 to 99 percent of the sludge is water, the disposal of 56 dry tons/ha/year of sludge would amount to a yearly supplemental water input of 5 to 50 cm. The soil permeability, moisture content, and regional evapotranspiration are the major hydraulic factors to be considered. When the soil becomes saturated, runoff occurs which can transport contained sludge constituents to surface waters. The supplemental water associated with landspreading of sludge, like precipitation, also recharges the soil mantle, and thus can transport soluble constituents to the groundwater.

The application of sludge to the soil increases the organic content of the soil or the soil humus. Humus is in a dynamic state, being decomposed continuously by microorganisms. It contains almost all major and minor plant nutrients, and its colloids have the property of adsorbing the soluble nutrients, thus preserving them from loss through leaching and making them available to plants. For example:

$$\underset{\text{microcline}}{KAlSi_3O_8} + H\ \text{humus} \longrightarrow \underset{\text{acid silicate}}{HAlSi_3O_8} + \underset{\text{adsorbed K}}{K\ \text{humus}}$$

Hence, the potassium is changed from a molecular to an adsorbed form, making it readily available to higher plants. It has been reported that the base exchange capacity of soils is directly related to the organic matter content [51].

Sewage sludge also contains considerable quantities of bases (calcium, magnesium, and sodium). Calcium and magnesium are also important trace plant nutrients. High applications of most sludges will tend to buffer the pH of soils. This is particularly of value to very acid soils such as acid mine spoil banks. Although of little plant food value, sodium is of importance since it assists in chemical changes which take place in the soil. In soils rich in clay and humus, the sodium cation liberates certain plant nutrients, including calcium, magnesium, potassium, and phosphorus. In light soil, sodium tends to hold moisture and aid capillary attraction. However, in municipal sludge calcium exceeds sodium so that no deleterious effects are expected from applying sludge to the land.

Liquid sludge as applied to the land contains major fertilizing elements (nitrogen, phosphorus, and potassium). The dry weight percentage of each, as earlier discussed, depends on the sewage and sludge treatment plant operations. Nitrogen, phosphorus, and potassium content of sludge can normally vary from 2 to 6 percent total N, 2 to 8 percent P_2O_5, and 0.2 to 0.8 percent K_2O on a dry weight basis.

Both mineral and organic nitrogen are contained in sludges. Part of the organic nitrogen of raw sludges is converted by digestion to mineral forms. The mineral nitrogen in digested sludge is mostly in the form of ammonium ions with small amounts of nitrite and nitrate ions. Much of the ammonium ion concentration can be lost through volatilization if the sludge is not immediately incorporated into the soil [7,16,22,27, 35,57].

The processes that affect the form of nitrogen in soils (mineralization, nitrification, denitrification, immobilization, fixation, adsorption, volatilization, cation exchange, convection, dispersion, and plant uptake) are extremely complex and may take place concurrently [12]. The fate of nitrogen in the sludge which is added to the soil is basically dependent on the levels of oxygen in the soil. Organic nitrogenous compounds are decomposed to ammonia by hydrolytic and oxidative mechanisms of numerous heterotrophic microorganisms. With normal soil conditions, ammonia in turn is converted by aerobic autotrophic bacteria into nitrites and nitrates. The nitrate form may be absorbed by plants or lost in leaching while ammonia is adsorbed by clay or humus particles. If anaerobic conditions are created in soil in the presence of carbon, denitrifying bacteria, and the proper temperature, denitrification of nitrates occurs with the usual evolution of nitrogen gas to the atmosphere. Studies show that in the sludge-soil environment, the rate of denitrification is independent of nitrate concentration, but denitrification proceeds at a slower rate then in a sludge environment alone [52].

The amount of nitrogen removed from the soil by plants is variable, with losses consisting of the nitrogen contained in the harvested crop since the rest returns to the soil as humus. The harvest of a good corn crop can remove 168 to 280 kilograms of nitrogen per hectare from the system. Some grasses can use more nitrogen. Annual application rates of sludge range from as low as 6.7 to as high as 359 tons per hectare of sludge solids. Twenty-two and one-half to thirty-three and one-half tons of Chicago sludge per hectare per year are required to supply the nitrogen needs of nonleguminous crops [53].

Many authors contend that the nitrogen is the first component that limits sludge application rates. If nitrate-nitrogen is applied or formed in amounts greater than can be removed by harvested plant uptake, denitrification, and microbial use, the excess nitrates can potentially contaminate ground and/or surface waters by leaching or runoff. Furthermore, excess nitrogen can also cause a high nitrate content in certain crops. Nitrate poisoning can result from the consumption of green forage which contains in excess of 0.3 percent nitrate (dry basis) [35].

Phosphorus is present in the sewage sludge in both organic and inorganic forms. The soluble phosphate is directly utilized by plant roots or adsorbed by mineral clay and humus particles. Phosphate in excess of crop needs is strongly held to the soil particles [45] and thus will remain as a valuable soil resource. Although phosphate concentrations in groundwater are virtually unknown, the soil capacity is not infinite. Phosphate pollution of surface water may be caused by soil erosion.

Most of the potassium content of sludge is in solution. Part of the potash is used by plants and the rest is absorbed by soil colloids or lost through leaching. Excessive quantities of available potassium in the soil tend to prolong the season of growth and thus delay the maturing of the crop [52] . However, the large amounts of cations in sludges can depress plant uptake of potassium. Because sludge contains relatively little potassium, even heavy applications of sludge may not provide sufficient potassium for optimum plant growth.

Sewage sludges contain an abundance of micronutrients, i.e., iron, manganese, boron, copper, zinc, molybdenum, etc. Small applications of sludge would normally be sufficient to correct any soil deficiencies. However, large quantities of microelements applied to soils may interact and induce deficiencies and/or toxicities. For example, high concentrations of zinc and copper have been reported as being responsible for the exhaustion of sewage-irrigated soil. It is also observed that high concentrations of one micronutrient could lead to deficiency of another. For example, the high concentration of molybdenum in lime-rich soils of the Paris sewage farm was considered partly responsible for the lack of manganese [54]. Upon review of published information related to the nature and effects of minor elements in sewage sludge amended soils, Page [72] reports that (1) the surface horizons of these soils are enriched in trace elements, with the extent of enrichment depending upon the composition of the sludge and the amount applied, (2) with the exception of sandy or very acid soils, a high percentage of trace elements (Ag, Ba, Cd, Co, Cr, Hg, Mn, Ni, Pb, Sn, and Zn) associated with the sludge organics are retained in the tillage layer, (3) plant yields and concentration of trace elements in the plant are dependent basically upon soil pH and the plant species, and (4) under certain conditions, the concentration of trace elements (Mo, Se, and Cd) can possibly reach levels which are sufficient to cause toxicities to livestock.

In addition to those heavy metals in sludge which are considered to be essential micronutrients, others such as chromium, mercury, cadmium, lead, and nickel may be beneficial to crop nutrition in certain concentrations, but there are limits to the concentrations that can be tolerated in agricultural soils. The organic matter and fine inorganic soil particles chelate or adsorb many metals such as zinc, copper,

and nickel [7] . Some authors indicate that a principal factor in retention of heavy metals is sorption of hydrous oxides of manganese and iron. Generally, maintaining oxidizing soil conditions and the pH neutral to slight alkalinity aids in immobilizing metals [53].

Although little metal migration in the soil is expected under normal conditions, the capacity of the soil to retain these elements must be limited [16] . Groundwater contamination through leaching is a potential problem; however, erosion of metal-bearing soil particles in surface water appears more probable [21] . The use of agricultural lime has been shown to immobilize most metals and reduce their availability to plants.

The absolute quantity of the metals added to the soil by landspreading of liquid sewage sludges may have little relation to the concentration that is available to plants. Factors including pH, organic matter, and other metals in the sludge and soil influence the availability of metals to plants. King and Morris [20] concluded that the application of anaerobically digested sludges (higher than average in heavy metals) had little effect on in-vivo digestibility of the Bermuda grass (Cyndon dactylon/L. Pers) forage. Applications did increase concentrations of N and Na in the plants but had little or no effect on yields. Rye (Secale cereole L.) yields were reduced when the sludge application exceeded about 112 dry tons per hectare per year. Reduced yields were probably due to high levels of Zn and Cu in the forage, rather than deficiencies of N, P, K, Ca, or Mg or high levels of Mn, B, Mo, or Al [13].

There appears to be a paucity of information relative to maximum tolerable concentrations of micronutrient and other trace elements in crops and animals. Accumulation of heavy metals in the soil from repeated sludge applications must also be considered. Conn [55] reports that copper and zinc soil concentrations in excess of 100 and 300 ppm, respectively, are toxic for plant growth. A report by Dean, et al [56], indicates that soil concentrations of nickel and zinc above 100 to 10 ppm, respectively, are toxic separately with respect to seed germination of tomatoes. The paper also indicates that 1000 ppm copper has little effect, while toxic effects can be pronounced below a composite concentration of 100 ppm of Zn, Cu, and Ni. The data shown in Table 9 are perhaps indicative of the increasing concentrations of heavy metals in the leaf and grain portions of corn under various application rates [53]. Sludge-borne metals applied to soils are not as readily toxic to plants as the same metals applied singly as a salt solution.

Discussions are often included in the literature relative to seed germination inhibition resulting from landspreading of freshly digested sludge. Hinesly and Sosewitz [18] concluded that corn and soybean

Table 9. METALS CONTENT OF CORN
(ppm oven dry basis) [53]
(presented in English units)

Rate of sludge (a) application (inches per week)	Zinc	Copper	Nickel	Cadmium
		Leaf		
0	58.0	8.9	2.8	3.3
1/4	85.0	9.0	1.3	3.0
1/2	137.8	10.2	2.6	5.3
1	212.0	8.7	4.3	11.6
		Grain		
0	88.8	5.2	2.28	0.30
1/4	93.0	6.3	3.03	0.60
1/2	127.0	5.2	2.18	0.79
1	152.3	5.6	3.08	1.03

(a) 136 tons of sludge solids per acre applied in 4 years at the maximum rate.

germination was inhibited partly because of the ammonium or ammonia content of fresh, anaerobically digested sludge. However, a paper by Molina, et al [57], states that inhibition of seed germination is not caused wholly by salt concentration nor the oxygen reduction potential of the medium. Other hypotheses to account for the observed phenomenon suggest that manganese or entrained digester gases such as H_2S may be the causative factor. The problem, however, is apparently avoided if the liquid sludge is stored in the open for a few weeks or landspreading practices are interrupted during seed germination. With respect to corn and soybeans, no associated problems have been observed during plant maturation.

SECTION IX

PUBLIC HEALTH CONSIDERATIONS

The incidence of disease transmission, particularly Shistosomiasis, associated with the "night soil" crop fertilization in China and the epidemics of typhoid fever in other parts of the world attributed to the consumption of raw vegetables irrigated with raw sewage have caused a general aversion to the use of even treated human waste products in the United States. The most recent incident of disease transmission in the United States which could be attributed to the consumption of foodstuffs grown on a sewage farm reportedly occurred in 1919. The consumption of blackberries or vegetables grown on the farm were believed to have caused typhoid fever in eight employees [58]. That most such outbreaks can be attributed to either the use of raw, untreated sewage or unsanitary food preparation and handling practices is generally not considered by the layman. Hence a "human waste stigma" has developed and acts as a constraint to the widespread acceptance and utilization of land disposal of treated wastewater sludges. The following sections summarize the significant literature on landspreading of liquid sludge relative to public health considerations along the following lines: occurrence and movement of pathogens in the soil, survival of pathogens in the soil, and health hazards posed to humans and animals.

MOVEMENT OF PATHOGENS IN THE SOIL

The potential for contamination of groundwater by pathogenic microorganisms is dependent on the ability of the pathogens to survive and move through the soil system. A number of factors including the types of soil involved, the number of microorganisms applied to the soil surface, and the many different kinds of microorganisms contained in both the soil system and the applied wastes all combine to complicate an assessment of pathogen movement in soils. Furthermore, there is a definite paucity of information on this subject specific to microorganisms introduced into the soil system through the application of liquid sludges. The majority of the research work in this area to date has been in conjunction with the disposal of wastewater effluents to the soil. Nevertheless, this work might well serve as an indicator of the behavior of pathogenic organisms applied to the soil via liquid sludges, albeit somwhat conservative as the amounts of water applied would be considerably greater in the disposal of wastewater effluents. In addition, land treatment systems for wastewater effluents are normally confined to

single site areas and involve much more frequent and heavier applications of water. Pathogens are more concentrated in sludge than they are in wastewater, but sludge stabilization processes kill most of the pathogens. So, the concentration of viable pathogens may be either higher or lower in sludge.

Much has been written on the various aspects which govern the movement of bacteria and viruses through the soil systems. McGauhey and Krone [50] and Krone [58] have comprehensively and critically reviewed the work of numerous investigators representing many scientific disciplines in order to assemble and interpret pertinent data on the use of soil as a wastewater treatment system. Generally, the conclusions of this review indicate that the movement of microorganisms through granular soils will not normally exceed more than 30.5 m laterally and that groundwater contamination should not be a serious hazard in granular, unfissured rock. For the most part, the information presented in this section summarizes the significant findings of McGauhey and Krone as they relate to the movement of bacteria and viruses through the soil systems.

Concerning the movement of viral pathogens, little information was reported in the literature until recently. However, the presence of viruses in sewage has been amply documented. For instance, one study isolated 150 viruses during the examination of 1,018 sewage samples. Of those identified, 31 were identified as ECHO, 4 as Polio, and 76 as Coxsackie. Thus, the possibility of survival and movement of viruses in the soil and percolating water is an important question.

One of the most significant studies relative to the movement of viruses in percolating waters and soil was contained in the report of the Santee Project near San Diego, California. Here, sewage was examined for viruses at each phase of treatment, i. e., raw sewage, activated sludge effluent, oxidation pond effluent, and effluent from six sand and gravel percolation beds. Reoviruses, Adenoviruses, and several types of Polio, ECHO, and Coxsackie viruses were identified at all times in the primary and secondary effluents, sometimes in the oxidation pond effluent, but never in the percolate from the soil system. Most recent data from the Santee Project were also reviewed by McGauhey and Krone. The data reflect composite samples taken each day of a 10-day sampling period from sampling wells located 122 meters downstream from the sand and gravel percolation beds. The percolation beds were 457 meters (1,500 feet) long and the flow rate in the gravel was about 61 meters in 2 days. The samples were analyzed for coliform bacteria, fecal coliforms. and fecal streptococci, and the results are presented in Table 10. The data indicate an impressive removal of bacteria by a very coarse medium.

On the basis of their review, McGauhey and Krone concluded that "both biological antagonisms and physical removal of cells characterize the change in bacterial quality of water percolating through a soil system; and that the soil system is a quite efficient device for removing bacteria".

Table 10. SUMMARY OF BACTERIOLOGICAL ANALYSES [50]
(Coliform, Fecal Coliform, and Fecal Streptococci)
All results are MPN/100 ml.

Sampling Station	Oxidation pond	200-ft well	400-ft well	Interceptor trench
Coliform bacteria				
No. of samples	29	29	29	28
Maximum	11 M[a]	3,300	35,000	22,000
Minimum	330,000	<180	78	20
Median	1.1 M	780	2,800	560
Fecal coliform				
No. of samples	29	29	29	28
Maximum	1.3 M	200	3,300	110
Minimum	4,500	<18	<18	<18
Median	210,000	<180	<180	<18
Fecal streptococci				
No. of samples	29	29	30	29
Maximum	490,000	54,000[b]	9,200[b]	230
Minimum	450	2	2	<1.8
Median	4,500	20	48	6.8

[a] M = million.

[b] Only one high result.

SURVIVAL OF PATHOGENIC ORGANISMS IN THE SOIL

In general, the occurrence and numbers of human pathogens in domestic sewage is a function of the general health of an area and of the shedding rate of various pathogens by infected humans. The bactericidal effects of sludge digestion are inhibitory, not necessarily lethal. Consequently, while present-day normal sewage treatment processes reduce the numbers of pathogenic organisms, they do not produce completely pathogen-free sludges.

With the practice of land disposal of liquid sewage sludge becoming more popular and widespread, the survival of pathogenic organisms in the soil, water, and on crops grown in sludge amended soils assumes increasing importance. This is especially true when one considers the many types of land to which sludge is being applied. Cropland, pastureland, woodland areas, highway median strips, and even public parks and golf courses are recipients of sludge. Consequently, the possibility that pathogenic

organisms contained in sludges could contribute to an uninterrupted human and/or animal disease cycle bears investigation.

That sewage sludge should be applied to the land with caution has been recognized for many years. For instance, in 1935 Tanner [59] stressed the importance of the persistence of pathogens by stating that "an important factor in epidemiology is the longevity of pathogenic bacteria in nature, for upon such longevity rests the ability of various agents such as foods to disseminate communicable diseases". While much appears in the literature concerning the pathogenic aspects of land disposal of sewage sludges, most of this information pertains to sludges which have been dewatered and either air dried or heat dried. The heat used for drying normally accomplishes the destruction of pathogenic microorganisms, while the long periods required to air dry the sludges are sufficient to also result in pathogen destruction. On the other hand, little has been published regarding the survival or persistence of pathogens introduced into the soil system via the application of liquid sewage sludges.

Rudolphs, et al [60] conducted an extensive review of the literature on the occurrence and survival of pathogens in soil, water, and on various types of vegetation irrigated or fertilized with sewage and sewage sludges. This review considered the most common intestinal pathogens which could cause disease by ingestion of contaminated raw vegetables or fruit--specifically the bacteria of three genera of the family Enterobacteriaceae: Salmonella, Eberthella, and Shigella.

Generally, the significant conclusions of this review were that fruits and vegetables grown on sewage irrigated or sludge amended soils can be contaminated with pathogenic microorganisms. Furthermore, the viability of these pathogens ranged from a few hours to several months. Among the factors which could influence the survival of pathogens in the soil and on vegetation, the following are the most significant:

(a) Type of organism - Escherichia coli, Eberthella typhosa, and Mycobacterium tuberculosis appear to be most resistant

(b) Temperature - lower temperature increases survival time

(c) Moisture - longevity is greater in moist soils than in dry soils

(d) Type of soil - neutral, high-moisture-holding soils favor survival

(e) Organic matter - the type and amount of organic matter present may serve as a food or energy source to sustain the microorganisms

(f) The presence of other microorganisms can have an antagonistic effect on the pathogens.

Dunlop [61] also reviewed the survival of pathogens and cited numerous examples of the variable survival rates of microorganisms in soil, water, and on crops. Table 11 presents a portion of the data extracted by Dunlop from the literature.

While extensive, the above reviews were not specific to soils which had been treated with liquid municipal sewage sludge. More recently, however, Kenner, et al [6], investigated specifically the persistence of pathogens in liquid sludge amended soils. The studies were conducted using two agricultural sites in Pennsylvania; St. Marys and Penn Townships. Neither site contained fecal coliforms, Pseudomonas aeruginosa, or Salmonella sp. prior to sludge application. Application rates and the type of sludge applied were as follows: St. Marys - anaerobically digested, activated sludge at the rate of 6.1 cm; Penn Township - anaerobically digested, activated sludge at the rate of 4.1 cm. Bacteriological assays of the sludges indicated that the St. Marys site received 1.8×10^7 fecal coliforms, 56,000 Ps. aeroginosa, and 414 Salmonella sp. per sq ft, while the Penn Township site received 2.5×10^7 fecal coliforms, 3.78×10^6 Ps. aeruginosa, and 5,678 Salmonella sp. per sq ft. Weekly soil samples from each site were analyzed over the period April 2, 1968, to August 27, 1968. For the St. Marys site, Salmonella sp. were not detected throughout the study and Ps. aeruginosa was detected only initially. Fecal coliforms, however, were still detectable at 21 weeks (192 per gram). Samples from the Penn Township site, however, showed 22 fecal coliforms per gram at 18 weeks, Ps. aeruginosa at 16 weeks, and Salmonella sp. up to 10 weeks.

Kenner also considered the effects of weather during late fall and winter months (November, 1969-June 8, 1970) on pathogen survival. Three plots of grass-covered ground were treated with (1) anaerobically digested primary sludge, (2) undigested primary activated sludge, and (3) undigested secondary activated sludge concentrated to 4 percent solids. The sludges were applied on November 5, 1969, at a rate of 4.1 cm, yielding the following number of pathogens per .093 m^2 (1.0 sq ft):

	Fecal coliforms	Ps. Aeruginosa	Salmonella sp.
Plot 1. Anaerobically digested primary sludge	1.48×10^7	1,300	1,098
Plot 2. Undigested primary activated sludge	1.09×10^8	41,600	2,800
Plot 3. Undigested secondary activated sludge (4 percent)	7.57×10^8	75,700	352,000

Table 11. SURVIVAL TIMES OF PATHOGENIC MICROORGANISMS IN VARIOUS MEDIA [61]

Organism	Medium	Type of application	Survival time
Ascaris ova	Soil	Not stated	2.5 years
	Soil	Sewage	up to 7 years
	Plants & fruits	AC(a)	1 month
Cholera vibrios	Spinach, lettuce	AC	22-29 days
	Cucumbers	AC	7 days
	Nonacid vegetables	AC	2 days
	Onions, garlic, Oranges, lemons, Lentils, grapes		
	Rice, dates	Infected feces	hours to 3 days
Endamoeba histolytica cysts	River water	AC	8-40 days
	Soil	AC	8 days
	Tomatoes	AC	18-42 hours
	Lettuce	AC	18 hours
Enteroviruses	Roots of bean plants	AC	At least 4 days
	Soil	AC	12 days
	Tomato & pea roots	AC	4-6 days
Hookworm larvae	Soil	Infected feces	6 weeks
Leptospira	River water	AC	5-6 days
	Soil	AC	15-43 days
Salmonella typhi	Dates	AC	68 days
	Harvested fruits	AC	3 days
	Apples, pears, grapes	AC	24-48 hours
	Strawberries	AC	6 hours
	Soil	AC	74 days
	Soil	AC	70 days
	Soil	AC	at least 5 days
	Pea plant stems	AC	14 days
	Radish plant stems	AC	4 days
	Soil	AC	up to 20 days
	Lettuce & endive	AC	1-3 days
	Soil	AC	2-110 days
	Soil	AC	Several months
	Lettuce	Infected feces	18 days
	Radishes	Infected feces	53 days
	Soil	Infected feces	74 days
	Soil	AC	5-19 days
	Soil	AC	70-80 days
	Cress, lettuce & radishes	AC	3 weeks
	Lake water	AC	3-5 days
Salmonella, other than typhi	Soil	AC	15-70 days
	Vegetables	AC	2-7 weeks
	Tomatoes	AC	Less than 7 days
	Soil	Sprinkled with Domestic sewage	40 days
	Potatoes	Sprinkled with Domestic sewage	40 days
	Carrots	Sprinkled with Domestic sewage	10 days
	Cabbage & gooseberries	Sprinkled with Domestic sewage	5 days
Shigella	Streams	Not stated	30 min-4 days
	Harvested fruits	AC	Minutes-5 days
	Market tomatoes	AC	At least 2 days
	Market apples	AC	At least 6 days
	Tomatoes	AC	2-7 days
Tubercle bacilli	Soil	AC	6 months
	Grass	AC	14-49 months
	Sewage	?	3 months
	Soil	?	6 months

(a) AC = artificial contamination

At approximately weekly intervals, 2-inch deep soil samples were taken and the number and kind of pathogens surviving determined. The maximum number of days which the pathogens survived are summarized as follows:

	Fecal coliforms	Ps. Aeruginosa	Salmonella sp.
Plot 1. Anaerobically digested primary sludge	147	119	56
Plot 2. Undigested primary activated sludge	147	147	112
Plot 3. Undigested secondary activated sludge (4 percent)	133	91	77

All of the above data suggest that pathogens can and do survive for varying periods in both the sewage sludge and the soils on which the sludge is spread.

POTENTIAL HEALTH HAZARDS

As pointed out earlier in this report, pathogenic organisms can and do survive the sewage treatment process and sludge digestion and can remain viable for varying lengths of time in the soil and on the vegetation growing on the soil. Therefore, whenever liquid sludge is handled, whether in transporting the material to lagoons for disposal or spreading the liquid sludge on land as part of a soil improvement program, the potential always exists for these pathogens to contribute to human and animal disease. The available information relative to public health hazards involved with land disposal of sludge leads to the belief that the risk to public health is slight.

For instance, Ewing and Dick [16] state that there is a great deal of public concern stemming primarily from an uncertainty of the fate of pathogenic agents and subsequent health hazards associated with land disposal practices. They also point out, however, that no incidence of disease transmission has been traced to sludge-disposal activities. In a review of the West Herfordshire sludge disposal operation, Seabrook [63] points out that public health officials do not feel the landspreading operation which disposes of 340×10^3 m^3 of liquid digested sludge per year on firm, easily drained gravel soils is a threat to public health. Stone [64] investigated numerous farms used for the disposal of sewage wastes in California and reported no particular difficulty with plant, animal, or human disease transmission. Sabey, et al [40], reported that where raw sewage is utilized, the health hazards are prevalent; but where well-digested sludge is used few if any health hazards are posed.

Most of the above discussion is concerned with the potential for transmission of diseases through the consumption of foodstuffs grown on waste-amended soils. That some pathogens can survive the sludge digestion process and remain viable in the soil for periods up to several months has prompted the general recommendation that liquid sludges should not be applied to root crops or crops intended for human consumption in the raw form. Adherence to this recommendation undoubtedly is responsible for the lack of public health problems in the United States relative to the land disposal of liquid sewage sludges.

Pastureland and farmland used to grow forage crops is frequently used as a land disposal site, and this is a practice which appears to present little problem from the standpoint of disease transmission via livestock grazing on such fields. Numerous studies have been reported [64] concerning the application of digested sludge and even raw sewage to pastureland, with no adverse effects accruing to the livestock.

Regarding pathogenic contamination of ground and surface waters, it has been reported that bacteria do not travel laterally more than 30.5 meters through granular soils, that complete removal of E. coli was noted in about 4.9 meters of dune sands, and viruses were removed in a 0.61 meter bed of clean sand at moderate rates of application over a 7-month period. Generally, then, groundwater contamination by pathogens may not be as much of a potential hazard as surface water contamination via surface erosion resulting from direct runoff from the sludge spreading operation or surface water runoff induced by snowmelt or rainfall. With careful site management, surface runoff can be controlled to essentially eliminate erosion. The important considerations along these lines have been discussed in the section on physiographic considerations.

It must be pointed out, however, that because of the variations of conditions that affect landspreading (i.e., quality of the sludge, general levels of public health prevailing in the area, site characteristics, soil characteristics, etc.), an evaluation of each active or proposed land disposal operation should be made before attempting to quantitatively predict the potential health hazards from a given operation. Also, there are means of disinfecting sludge prior to landspreading. The methods include long-term storage, pasteurization, addition of lime, and disinfection with chlorine or other chemicals; these have been considered in a previous section of this report.

SECTION X

LAND ACQUISITION

Since landspreading utilizes the land as a means of ultimate disposal, adequate amounts of suitable land must be continually available to accept the quantities of liquid sludge generated at the wastewater treatment plants. Both the literature review and the survey conducted as part of this program revealed a wide range of land types currently utilized to receive the liquid sludge. The most common land type by far is agricultural, both cropland and pastureland. Other types encountered included public parks, golf courses, airports, abandoned strip mines, cemeteries, plant grounds, highway median strips, woodlands, and landfill operations (both active and abandoned). Others were encountered, but not with the frequency of those listed above.

This section will review the problems of acquiring sufficient amounts of suitable land from two viewpoints: obstacles to land acquisition and land availability.

OBSTACLES

Two obstacles can prevent acquisition of land for sludge spreading. There are public fears of alleged health hazards and potential nuisances associated with landspreading and the high cost and scarcity of suitable land areas. Each of these objections would appear to be of a social nature both in implication and solution. For instance, one individual [65] reports that resistance is offered by people who simply do not want wastes used around them regardless of how helpful or ecologically safe they are. The static provided by such groups may be more limiting to landspreading than economic or technological factors.

Esthetic effects can also promote adverse public reaction to spreading of liquid sludges on the land. Generally, the major esthetic problem stems from odors generated at the site resulting from spreading of inadequately stabilized sludges. Along this line, Stone [66] reports that prior to the adoption of sludge digestion, some English sludge farms had notorious reputations for odor production. The resulting public opposition persisted even after sludge digestion eliminated most of the problems. This prompted Stone to conclude that "such is the power of the human mind over matter that complaints of disgusting stench

and revolting conditions are made which bear no relation to sensory experience". A similar experience was noted [65] in regard to a planned sludge spreading operation in Illinois. One individual complained of the "terrible, horrible stink of the sludge" before sludge spreading was started.

Probably the most frequently stated objection to land disposal of liquid sewage sludge relates to potential health hazards. These concerns are felt by some [67] to be more a function of land treatment's visibility as a disposal method than a function of real risk to public health. While many individuals readily accept the use of farmyard manures, they have a reluctance to regard properly treated and utilized human wastes in the same way [66]. Although potential for disease transmission via a carefully managed landspreading operation is quite low, this information must be communicated to the general public in attempts to allay fears of disease transmission. Meanwhile, this "human waste stigma" can be a very real constraint to the acquisition of adequate amounts of suitable land areas.

Although small communities can usually find suitable land for sludge disposal at no cost to the treatment plant operation, there are instances where the purchase of land would be desirable to enable complete control over the operation and to ensure continuity of the practice. The new Federal Water Pollution Control Act Amendments of 1972 under Title II, "Grants for Construction of Treatment Works", Section 212(2) (2), now permits acquisition of the land that will be an integral part of the waste treatment process or will be used for ultimate disposal of residues resulting from such treatment [68].

LAND AVAILABILITY

Each landspreading activity should be examined on the basis of the goals intended for the particular operation, i.e., a disposal operation only or a disposal operation as part of a soil improvement program. The frequency and rate of application and the type and amount of land required (and hence its availability) are largely influenced by the stated objective.

If one considers the total amount of land potentially available for use in sludge disposal activities in the United States, it would appear that the nation's land resources need be in no danger from sludge disposal. For instance, on the basis of 1965 data, some 1.3 million hectares of land have been disturbed by surface mining activities [67]. Six states were reported as containing over 40,500 hectares each which required reclamation. These are

- Pennsylvania 92,900 hectares
- Ohio 69,500 hectares
- Florida 58,100 hectares
- Texas 55,200 hectares
- West Virginia 45,100 hectares
- California 43,100 hectares.

These six states account for more than 31 percent of the total United States population. In addition, most major United States cities are located within 16 kilometers of such areas, which is within the limits that sludges can be economically transported by truck, rail, or pipelines [69].

With regard to agricultural land, Carlson [70] states that such land will be used more and more for waste disposal, either in conjunction with cropping or replacing cropping for utilization as disposal sites only. The United States presently has some 144 million hectares of cropland, over 410 million hectares of forest and range land, and 205 million hectares of nonagricultural land. On an assumed worst case, Carlson further estimates that all of our decomposable municipal wastes could be disposed of on less than 5 percent of our cropland without harm to the resource. Distribution rather than the capacity of the total system to assimilate the wastes becomes the problem.

SECTION XI

SURVEY OF SEWAGE TREATMENT PLANTS IN FEDERAL REGIONS 2, 3, 4, 5, and 9

The comprehensive literature survey conducted as an integral element of this program revealed the existence of a large body of written matter on land disposal systems and techniques relative to waste water effluents, organic composts, and both liquid and dried sewage sludge. As a whole, however, the major portion of the information relative to land disposal of liquid sewage sludges can be placed in a category best described as "how we are conducting our landspreading operation". As such, this information relates primarily to the mechanics of individual landspreading operations, many of which are located in Europe and England. While most European operations are associated with raw sewage farms, surveys have shown that approximately 40 percent of all municipal treatment works in England are now using landspreading for the disposal of liquid digested sludges [63].

Until recently, however, the practice of landspreading of liquid sewage sludge was not widely observed in the United States. Rather, these sludges were often treated as "waste products" of society and, accordingly, were disposed of with too little attention given to their potential usefulness or resource value. Now, however, this practice is increasing in popularity in the United States. Although the initial interests were directed primarily toward the liquid portion of treated sewage in water deficient regions, there are many situations where the disposal of the liquid sludge by landspreading may offer an ultimate and an economical solution to the waste disposal problem while at the same time providing for a beneficial use of resources which might otherwise be wasted.

Since the vast majority of active landspreading activities are not reported in the open literature, a literature review will not yield an accurate estimate of the proportion of U. S. sewage treatment plants which are routinely disposing of their liquid sludges via landspreading. Furthermore, an examination of the most recent inventory of municipal waste facilities [71], while providing information on sludge treatment and disposal methods, does not yield a reliable estimate of the extent to which landspreading is currently practiced in the United States. Also, most state agencies either do not compile such information, or are just beginning to assemble the information and therefore cannot readily provide it.

An integral element of this program was, therefore, to obtain a relatively accurate estimate of the proportion of the United States sewage treatment plants routinely using landspreading for the disposal of liquid sludges. Consequently, a combination mail and phone survey was conducted involving all sewage treatment plants, 3.8×10^3 m^3/day or greater, in the following five Federal Regions:

Region 2 - New York and New Jersey

Region 3 - Pennsylvania, Maryland, Delaware, Virginia, and West Virginia

Region 4 - Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, and Florida

Region 5 - Minnesota, Wisconsin, Michigan, Ohio, Indiana, and Illinois

Region 9 - California, Nevada, and Arizona.

These regions were selected on the basis of the total population involved and on the fact that they represent the range of climate, topography, and soil conditions to be encountered throughout the United States.

Another important element of this phase was to conduct field visits to some selected landspreading operations. The purpose of these field visits was to attempt to obtain pertinent unreported data and to prepare case history writeups based upon observation of the operations and interviews with the plant personnel.

The following sections discuss these two phases of the program.

QUESTIONNAIRE AND PHONE SURVEY

A review of the 1968 Inventory of Municipal Waste Facilities revealed that the compilation did not appear to be a reliable record of facilities which used landspreading for the disposal of liquid sludge. The Inventory, however, did represent the single best source for the identification of the total number of treatment plants by Federal Region, state, and plant size. Thus, the Inventory was used to identify, and initially stratify, the population from which the facilities to be contacted were derived.

Although some 9,891 sewage treatment plants were identified in the five Federal Regions of interest, it was concluded that the best population to be surveyed could be formed by (1) elimination from

consideration all plants smaller than 3.8×10^3 m^3/day and (2) elimination of those communities and facilities listed in the 1968 inventory that were being served by other communities or facilties. The reasoning behind the eliminating of smaller plants involved considerations of the ability to collect data. Also, many of the plants with design inflow less than 1 mgd are package plants and essentially unmanned. Therefore, it was felt that the response to a mail and/or phone survey from the less than 3.8×10^3 m^3/day plants would not warrant the effort of contact and, further, that available data from these operations would be severely limited. It was further concluded that serviced communities could be more expeditiously contacted by surveying the parent organization.

The screening process yielded 1,909 plants stratified by Federal Region and plant size as follows:

Plant size, 10^3 m^3/day	Region					
	2	3	4	5	9	Total
3.8-38.0	247	270	466	444	211	1,638
38-380	38	26	40	82	51	237
> 380	12	6	3	9	4	34
Total	297	302	509	535	266	1,909

A copy of the questionnaire mailed to the above population is shown in Figure 3. As the primary objective of the mail survey was to obtain an estimate of the number of plants using landspreading in the five Federal Regions of interest, the decision was made to keep the questionnaire short and simple in order to elicit the highest possible response.

Table 12 summarizes the results of the mail survey. Briefly, a 40 percent response to the mail survey was achieved, with the best response (55 percent) coming from Region 5. The remaining Regions responded in the following percentages: Region 2 - 28 percent, Region 3 - 35 percent, Region 4 - 32 percent, and Region 9 - 38 percent.

Based upon the actual number of responses, the percent response to each of the categories of Question 1 of the questionnaire are summarized as follows:

1A. Landspreading is used on a routine basis - 25 percent

1B. Landspreading has not been used - 57 percent

1C. Landspreading was used, but discontinued - 7 percent

Form Approved
OMB No. 158-S 72024

Name of Facility _____

Address _____

Name and Phone Number of Person Responding _____

_____

1. Check the one which best describes your plant's operation with respect to landspreading of liquid municipal sewage sludge.

   ☐ a. Landspreading is currently used on a routine basis.

   ☐ b. Landspreading has not been used.

   ☐ c. Landspreading was used, but has been discontinued.

   ☐ d. Landspreading will be used in the future.

   ☐ e. Landspreading was considered, but rejected.

2. If you checked 1a, please answer the following:

   a. How many years has your plant used landspreading? _____

   b. How is landspreading presently conducted at your plant?

      ☐ By plant personnel. ☐ By contract hauler. ☐ As a give-away operation. ☐ Other (please specify) _____

      _____

   c. What means are used to transport the sludge to the landspreading site? ☐ Tank Truck ☐ Pipeline ☐ Barge ☐ Railroad ☐ Other (please specify) _____

   d. Distance to landspreading site. _____ miles

   e. What kind(s) of land is used for the landspreading operation? ☐ Farmland ☐ Abandoned strip mine ☐ Parks ☐ Highway median strips ☐ Other (please specify) _____

   f. What type(s) of spreading equipment is used? ☐ Tank Truck ☐ Spray Irrigation ☐ Sprinkler Irrigation ☐ Irrigation Pipe ☐ Sub-sod Injection ☐ Other (please specify) _____

      _____

FIGURE 3. Questionnaire Used in Mail Survey

Table 12. SUMMARY OF THE MAIL SURVEY RESPONSE

Plant size 10^3 m^3/day	Number mailed	Number of responses	Percent response	IA. LS* used on regular basis		IB. LS not used		IC. LS was used, but discontinued		1D. LS will be used		IE. LS was considered, but rejected	
				No.	%	No.	%	No.	%	No.	%	No.	%
Region 2													
3.8-38	247	68	28	5	7	51	75	5	7	5	7	2	3
38-380	38	11	29	-	-	10	91	-	-	-	-	1	9
> 380	12	3	25	-	-	2	67	1	33	-	-	-	-
Region 3													
3.8-38	270	91	34	25	27	57	63	4	4	4	4	1	1
38-380	26	13	50	4	31	7	23	-	-	2	15	-	-
> 380	6	3	50	-	-	3	100	-	-	-	-	-	-
Region 4													
3.8-38	466	142	30	28	20	88	62	9	6	16	11	1	-
38-380	40	17	43	2	12	12	71	2	12	1	6	-	-
> 380	3	3	100	-	-	1	33	-	-	2	67	-	-
Region 5													
3.8-38	444	233	52	94	40	94	40	15	6	21	9	9	4
38-380	82	57	70	10	18	30	53	5	9	6	11	6	11
> 380	9	4	44	1	25	2	50	1	25	-	-	-	-
Region 9													
3.8-38	211	75	36	12	16	51	68	4	5	4	5	4	5
38-380	51	23	45	2	9	16	70	3	13	2	9	-	-
> 380	4	2	50	-	-	1	50	-	-	-	-	1	50

*Landspreading

ID. Landspreading will be used - 8 percent

IE. Landspreading was considered, but rejected - 3 percent

Because the problem of nonrespondents is characteristic of all data-gathering schemes utilizing mail surveys, a follow-up phone survey was conducted in an attempt to develop a more accurate estimate of plant landspreading operations. All plants with greater than 380 x 10^3/m^3/day volume within the five Federal Regions were contacted. Since the mail response from Regions 2 and 5 was lowest and highest, respectively, follow-up phone calls to randomly selected nonrespondents were initially concentrated in these regions to verify the mail survey results.

An analysis of the two samples (e.g., phone and mail survey) by region and plant size indicated that the samples were statistically different. In all cases, it was the mail survey which suggested the higher estimate of the percentage of treatment plants that are using landspreading on a routine basis. On this basis, it was decided that follow-up phone calls to a sample of nonresponding plants in Regions 3, 4, and 9 would be conducted to further increase the confidence on the survey estimates of plants using landspreading in these three regions. The results of the completed mail and phone survey are included in Table 13.

Of the 987 respondents to the survey, 225 (22.8 percent) are currently using landspreading on a routine basis. Applying the survey results on a region-by-region basis to the total population sampled suggests that about 400 plants (21 percent) are presently practicing landspreading.

Utilization of landspreading of liquid sewage sludge is most dominant in Region 5 (Ohio, Indiana, Illinois, Michigan, Minnesota, and Wisconsin). The survey indicated thatthe percentage of plants using landspreading is least in Region 2 (New York and New Jersey). The characteristic plant size using landspreading in the regions surveyed is less than 380 x 10^3/m^3/day. Figure 4 demonstrates the geographic distribution of those plants which responded as using landspreading.

Table 14 summarizes the results of the mail and phone survey by individual plants. Briefly, the summary table indicates that the majority of the plants which responded as using landspreading are secondary activated sludge plants in the (3.8-19.0) x 10^3 m^3/day size class. Utilization of plant personnel to conduct transport and spreading operations constitutes normal practice. With the exception of Chicago, Illinois, no transport systems involving barges or railroad tank cars were identified. The use of pipeline sludge transport systems identified in the survey are for the most part restricted to those less than 1.6 kilometers in length. The most common transport system involves the use of a tank truck with the distance to the landspreading site being normally less than 16 kilometers one way.

Table 13. LANDSPREADING SURVEY RESULT

Plant size $10^3 \times m^3$/day	Total plants	Total Responding		Number of respondents using landspreading		Estimated percentage of plants using landspreading	Percentage standard deviation	Projected number of plants using landspreading
		Mail	Phone	Mail	Phone			
Region 2								
3.8-38	247	67	73	5	1	3.02	0.80	8
38-380	38	11	10	0	0	0.00	0.00	-
> 380	12	3	9	0	0	0 plants are spreading		-
Region 3								
3.8-38	270	88	-	25	-	28.4	4.00	77
38-380	26	13	9	4	1	22.7	3.50	6
> 380	6	3	3	0	3 (trial)	0 plants are spreading		3
Region 4								
3.8-38	466	142	-	28	-	19.7	2.80	92
38-380	40	17	6	2	0	8.7	3.90	4
> 380	3	3	-	0	0	0 plants are spreading		-
Region 5								
3.8-38	442	235	107	94	34	36.1	1.50	160
38-380	82	54	18	10	2	16.0	1.60	13
> 380	9	4	5	1	1 (trial)	1 plant is spreading		1
Region 9								
3.8-38	211	76	-	12	-	15.8	3.40	33
38-380	51	21	6	2	0	7.4	3.50	4
> 380	4	2	2	0	0	0 plants are spreading		-
Totals	1,907	739	248	183	42			401

TABLE 14. SUMMARY OF RESPONSES BY IND

Plant Name	Plant Size, 10^3 m^3/day	Type of Sewage Treatment: Primary: Mech. Cleaned	Primary: Other	Secondary: Low Rate Trickling Filter	Secondary: High Rate Trickling Filter	Secondary: Activated Sludge	Secondary: Other	No. of Years	Conduct of Landspreading Operation: Plant Personnel	Conduct of Landspreading Operation: Other	Means of Sludge Transp: Tank Truck	Means of Sludge Transp: Other
Region 2												
Clinton, New Jersey	3.8					X		3		Contract Hauler	X	
Avon, New York	10.6		Imhoff Tanks					--	X			Tractor + Liquid Manure
Westfield, New York	5.7			X				20		Contract Hauler	X	
Woodridge, New York	3.8			X				4		Contract Hauler	X	
Region 3												
Anne Arundel Co., Md.	39.9					X		10	X		X	
Bethlehem, Pa.	47.5				X							
Carlisle, Pa.	9.5			X				10		Contract Hauler		
Chambersburg, Pa.	11.4			X				10	X		X	
Ebensburg, Pa.	5.3			X				8	X		$3 m^3$	
Elizabethtown, Pa.	4.9			X				25	X		X	
Ephrata, Pa.	7.2			X				6	X	Contract Hauler	X	
Gettysburg, Pa.	3.8			X				10	X			Pipeline
Greater Greensburg S.A.	11.3					X		3	X		X	
Greencastle, Pa.	13.8				X			10	X		X	
Grove City, Pa.	3.8					X		9	X		X	
Kingstown, Pa.	3.8			X				1		Contract Hauler	X	
Lebanon, Pa.	24.7						Extended Aeration	6	X		X	
Palmyra, Pa.	3.8			X				16	X		X	
Penn Twp., Pa.	18.6					X		10		Contract Hauler	X	
Philadelphia, Pa.												
Northeast Plant	532					X						
Southeast Plant	418						Chemical					
Southwest Plant	426						Chemical					
St. Marys, Pa.	5.3					X		5	X		X	
Sharon, Pa.	12.5						Plain Aeration	2		Contract Hauler	X	
Shippensburg, Pa.	6.1			X				13	X		X	
Somerset, Pa.	3.8				X			1		Other Borough Employees	X	
Waynesboro, Pa.	5.7			X				20	X		X	
Wyomissing Valley JMA, Pa.	7.6				X			12		Contract Hauler	X	
York, Pa.	68.4					X		17	X		X	
Charlottesville, Va.	16.0				X			12	X		X	
Danville, Va.	26.6	X						13	X		X	
Front Royal, Va.	4.6	X						15	X		X	
Harrisonburg, Va.	8.7				X			10	X		X	
Martinsville, Va.	15.						Plain Aeration	5	X		X	
Norfolk, Va.	91.2	X						24	X			
Region 4												
Florence, Ala.	13.3	X						4	X		X	
Avon Park, Fla.	4.6					X		--	X		X	Pipeline
Fort Myer, Fla.	22.8				X			1		Contract Hauler	X	
Fort Pierce, Fla.	19					X		15	X		X	
Hollywood, Fla.	34.7				X			1	X			Pipeline
Miami, Fla.	379					X		11	X			Pipeline
Milton, Fla.	6.5				X			1	X		X	
Ocala, Fla.	8.7			X				14	X		X	
Perrine (Miami), Fla.	6.8					X		1	X		X	
St. Petersburg, Fla.												
Plant No. 1	29.1					X		2	X		X	
Plant No. 2	15.2	X						2	X		X	
Plant No. 3	46.7					X		2	X		X	
Plant No. 4	76	X						2	X		X	
Sarasota, Fla.	15.2				X			1	X		$15.1 m^3$	
Tallahassee, Fla.	30.8				X	X		14	X		X	
Winter Park, Fla.	7.6					X		6	X		X	
Macon, Ga.	53.2				X			9	X		X	
Rome, Ga.	22.8				X			3	X		X	
Georgetown, Ky.	4.9			X				4	X		X	
Hopkinsville, Ky.	11.4				X			5	X		X	
Winchester, Ky.	7.6				X			2	X		X	
Meridian, Miss.	19					X		5	X			Pipeline
Concord, N.C.	22.8				X			7	X			Other
Elizabeth City, N.C.	4.9						Not Specified	2	X		X	
High Point, N.C.	45.6					X		5	X		X	Pipeline
Cleveland, Tenn.	22.8			X				1	X		X	

TABLE 14. SUMMARY OF RESPONSES BY INDIVIDUAL PLANTS

No. of Years	Conduct of Landspreading Operation: Plant Personnel	Conduct of Landspreading Operation: Other	Means of Sludge Transportation: Tank Truck	Means of Sludge Transportation: Other	Distance to Site, km	Kinds of Land Used: Farm Land	Kinds of Land Used: Other	Kinds of Spreading Equipment: Tank Truck	Kinds of Spreading Equipment: Other	Comments
3		Contract Hauler	X		1	X		X	Sprinkler Irrigation	Aerobically Digested Sludge
--	X			Tractor + Liquid Manure Spreader	2	X			Liquid Manure Spreader	
20		Contract Hauler	X		2-8	X		X		
4		Contract Hauler	X		2-5		Old City Dump	X		
10	X		X		3-24	X		X	Irrigation Pipe	
10		Contract Hauler			8-16	X		X		Liquid Sludge Provided Free to Landowners
10	X		X		24	X		X		
8	X		3 m^3		8	X		X		
25	X		X		6	X		X		
6	X	Contract Hauler	X		2-8	X		X		
10	X			Pipeline	.5	X		X		
3	X		X		10	X		X		
10	X		X		1-2	X		X		
5	X		X		18	X	Strip mine	X		
1		Contract Hauler	X		3-5	X		X		
6	X		X		6-8	X		X		
16	X		X		3	X	Orchards	X		
10		Contract Hauler	X		32		Strip mine	X		
										Trial Basis
										Trial Basis
										Trial Basis
9	X		X		5-8	X	Strip mine	X		
2		Contract Hauler	X		0	X		X	Irrigation Pipe	
13	X		X		.5	X		X		
1		Other Borough Employees	X		7.5	X		X		
20	X		X		1	X		X		
12		Contract Hauler	X		8	X		X		
17	X		X		7-32	X		X		
12	X		X		11-25		Strip mine		Spray Irrigation & Subsoil Inject.	
15	X		X		2-8	X		X		
15	X		X		.5	X		X		
10	X		X		1	X		X		
5	X		X		8	X		X		Tank Truck Equipped With Directable Spray Nozzle
25	X		X		6-8		Golf Course	X	X (Temporary)	Private Trucks Account for 50 Percent of Hauls
4	X		X		19	X		X		
--	X		X	Pipeline	Plant Grounds				Irrigation Pipe	
1		Contract Hauler	X		8-13		Farm	X		Land Used Includes Golf Courses, Pasture Land, Pumpkin Groves
15	X		X		10	X		X		
1	X			Pipeline	Plant Grounds				Irrigation Pipe	Required by Local Authorities to Keep Sludge on Plant Site
11	X			Pipeline	.5				Irrigation Pipe	
1	X		X		5-6		Woodland Area	X		
23	X		X		8-32	X		X		
1	X		X		10		Mangrove Marshland	X		
2	X		X		2-5		Farm, Golf Courses	X		
2	X		X		2-8		Farm, Golf Courses	X		
2	X		X		2-8		Farm	X		
2	X		X		2-8		Farm, Golf Courses	X	Sludge & Furrow	
1	X		18.4 m^3		16	X		X		
14	X		X		6		Airport	X		
3	X		X		18		Orange Groves	X		
3	X		X		2		Stripmine	X		Land Used to Grow Hay for Sale
3	X		X		--	X	Plant Grounds	X		
8	X		X		3-10	X		X		
5	X		X		5	X		X		
7	X		X		6	X		X		
3	X			Pipeline	.034	X			Irrigation Pipe	Soil is Settling
7	X			Other	.5	X				Other Transportation & Application = 5.3-m^3 Tractor-Drawn Liquid-Manure Spreader
2	X		X		3-5		Farm	X		
9	X		X	Pipeline	Plant Grounds			X	Irrigation Pipe	
1	X		X		Plant Grounds			X		

TABLE 14. (Continued)

Plant Name	Plant Size, 10^3 m^3/day	Type of Sewage Treatment: Primary: Mech. Cleaned	Primary: Other	Secondary: Low Rate Trickling Filter	Secondary: High Rate Trickling Filter	Secondary: Activated Sludge	Secondary: Other	No. of Years	Conduct of Landspreading Operation: Plant Personnel	Conduct of Landspreading Operation: Other	Means of Sludge Transportation: Tank Truck	Means of Sludge Transportation: Other	Means of Sludge Transportation: Distance to Site, km	Kinds of Land Use: Farm Land	Kinds of Land Use: Other
Region 4 (Cont.)															
Cookeville, Tenn.	16.0				X			4	X		X		6	X	
Johnson City, Tenn.	22.0	X						2	X		X		5	X	
Lewisburg, Tenn.	4.1			X				1	X		X		3-5		Park
Pulaski, Tenn.	8.7			X				3	X		X		3	X	
Region 5															
Addison, Ill.	4.6						Contact Aeration	3	X		X		2		Plant Grou
Belleville, Ill.	31.9						Extended Aeration	3	X		X		1-6	X	
Carbondale, Ill.	9.9					X		2	X			Pipeline	5-1	X	
Chicago, Ill.	3444			X	X	X		3	X	Contract Hauler		Pipeline, Barge, + Rail Road	1-928	X	Scrip
Dixon, Ill.	12.5					X		4		Contract Hauler	X		3	X	Pasture Land
East Moline, Ill.	9.5	X													
Freeport, Ill.	11.4	X						--	X		X		9-16	X	Golf Cou
Herrin, Ill.	4.6			X				6	X		X		6	X	
Litchfield, Ill.	3.8				X			14		Contract Hauler	X		6	X	
Marion, Ill.	10.6					X		--	X		X		6-8	X	
North Shore S.D., Ill.	48.6					X		6		Contract Hauler	X		48	X	
Olney, Ill.	4.9			X				41	X		X		10	X	
Robinson, Ill.	3.8			X				2	X		X		8	X	
Springfield, Ill.	60.0					X		8	X			Pipeline	.5	X	
Alexandria, Ind.	3.8				X			10	X		X		2-11	X	
Anderson, Ind.	86.3					X		10	X		X		2-15	X	
Auburn, Ind.	10.6					X		6	X		X		2-8	X	
Beech Grove, Ind.	4.6					X		10	X		X		9		City Dum
Bloomington, Ind.	26.5				X			1	X		X		3	X	
Bluffton, Ind.	4.9			X				9+	X		X		5	X	
Clarksville, Ind.	3.8						Plain Aeration	8	X		X		6	X	
Columbia City, Ind.	3.8					X		11	X		X		9	X	Plant Grou
Columbus, Ind.	20.1					X		10	X		X	Pipeline	.5-8	X	
Connersville, Ind.	18.2					X		17	X		X		3	X	
Crawfordsville, Ind.	6.8					X		1		Contract Hauler	X		16	X	
Edinburg, Ind.	3.8				X			9	X		X		9		Garbage Dum
Frankfort, Ind.	13.3				X			8	X		X		--	X	Golf Cou
Goshen, Ind.	13.3					X		7	X		X		5	X	
Greencastle, Ind.	4.9					X		3	X		X		.5-6	X	
Greenfield, Ind.	6.8			X				1	X		X		9	X	
Greenwood, Ind.	3.8					X		25	X			Plastic Hose	--		Plant Grou
Hobart, Ind.	8.0					X		4	X		X		--	X	
Kendallville, Ind.	8.5				X			19		Contract Hauler	X		8	X	
Lawrence, Ind.	6.8					X		5	X		X		10	X	
Lebanon, Ind.	7.6			X				9	X		X		9-6	X	Park
Marion, Ind.	45.6					X		50	X		X		5-16	X	
Martinsville, Ind.	4.9	X						12	V		X		.022	X	
Muncie, Ind.	98.3					X		6	V		X		8	X	
New Castle, Ind.	22.4					X		19	V		X		--		Plant Grou
North Manchester, Ind.	4.9					X		7	V		X		--		Plant Grou
North Vernon, Ind.	7.6				X			15	V		X		9	X	
Peru, Ind.	13.3					X		9	V		X		16	X	
Plymouth, Ind.	5.7					X		7	V		X		--		Plant Grou
Rochester, Ind.	3.8				X			11	V		X		4-16	X	
Rossville, Ind.	5.3				X			6	V		X		--	X	
Shelbyville, Ind.	9.9				X			10	V		X		.5	X	
South Bend, Ind.	182					X		4	V			Pipeline	5		X
Speedway, Ind.	22.8				X			17	V		X		2		Landfi
Union City, Ind.	3.8			X				9+	V		X		5	X	
Wabash, Ind.	10.6					X		6	V		X		9-10	X	Park
Washington, Ind.	6.5				X			10	V			X	2	X	
Adrian, Mich.	19.0					X		2	V		X		6	X	
Cadillac, Mich.	7.6					X		8	V		X		3		Airpo
Hillsdale, Mich.	8.7			X				4	V		X		5		Airpo
Howell, Mich.	4.9					X		2	V		X		11	X	
Lathgton, Mich.	3.8	X						2	V		X		6	X	
Monroe, Mich.	22.8	X						1		Contract Hauler	X		--		
Tecumseh, Mich.	5.3					X		2	V		X		--		Plant Grou
Traverse City, Mich.	24.7	X						1	V		X		9		Airpo
Albert Lea, Minn.	7.6				X			3	V		X		5-6	X	Park
Austin, Minn.	19.5				X			15	V		X		5-16	X	
Detroit Lakes, Minn.	8.3				X			15	V			Pipeline	.07		X
Fairmont, Minn.	11.4			X				10	V		X		2-5	X	
Faribault, Minn.	11.5					X		10	V		X		2	X	Park
Fergus Falls, Minn.	7.6				X			5	V		X		3-5	X	Park
Litchfield, Minn.	7.6					X		3	V		X		2-5	X	Park,
Little Falls, Minn.	3.8				X			10	V		X		3		Airpo Golf

TABLE 14. (Continued)

Handling Operation	Means of Sludge Transportation			Kinds of Land Used		Kinds of Spreading Equipment		Comments
Other	Tank Truck	Other	Distance to Site, km	Farm Land	Other	Tank Truck	Other	
	X		6	X		X		
	X		5	X		X	Spray Irrigation	
	X		3-5		Park	X		
	X		3	X		X		Soil Settles When Dried Sludge is Disked Under
	X		2		Plant Grounds	X		
	X		1-4	X		X		
		Pipeline	5-1	X			Spray Irrigation	
Contract Hauler		Pipeline, Barge, + Rail Road	1-920	X	Strip mine		Spray Irrigation, Irrigation Pipe, Subsoil Inject., Flow-Down Ejection	
Contract Hauler	X		?	X	Pasture Land	X		
	X		5-16	X	Golf Course	X		Landspreading Operation Conducted Periodically as Requested by Farmers
	X		8	X		X		
Contract Hauler	X		8	X		X		
	X		6-8	X		X		
Contract Hauler	X		48	X			Spray Irrigation	
	X		10	X		X		Tank Truck has 90° Turndown With Splash Plate
	X		4	X		X		
		Pipeline	.5	X			Spray Irrigation	Have Also Used Ridge & Furrow Flooding - Sites are Underdrained With Underdrainage Returned to Plant
	X		2-11	X		X		
	X		2-15	X		X		
	X		2-8	X		X		
	X		?		City Trash Dump	X		
	X		3	X		X		
	X		5	X		X		
	X		6	X		X		Pay Farmer $100/Month to Spread Liquid Sludge
	X		9	X	Plant Grounds	X	<- -	
	X	Pipeline	.5-6	X		X	Irrigation Pipe	Liquid Sludge Pumped .5 kilometers to Field Using Gated Irrigation Pipe
	X		3	X		X		
Contract Hauler	X		16	X		X		
	X		?		Garbage Dump	X		
	X		-	X	Golf Course	X		
	X		5	X		X		
	X		.5-6	X		X		
	X		?	X		X		
		½" Plastic Hose	-		Plant Grounds		½" Plastic Hose	
	X		-	X		X		
Contract Hauler	X		8	X		X		
	X		10	X		X		
	X		5-6	X	Park	X	Spray Irrigation	
	X		5-16	X		X		
	X		.022	X		X		
	X		4	X		X		
	X		-		Plant Grounds	X		
	X		-		Plant Grounds	X		Need a New Site
	X		?	X		X		
	X		16	X		X		
	X		-		Plant Grounds	X		
	X		<10	X		X		
	X		-	X		X		
	X		.5	X		X		
		Pipeline	0		X		Irrigation Pipe	28.5 hectares of Plant Property are Disked for Sludge Application
	X		2		Landfill	X		
	X		5	X		X		
	X		5-10	X	Park	X		
		X	?	X			Spray Irrigation, X	Other Transportation and Application Means = Tractor Pulled 9.8 m^3 Tank Wagon
	X		8	X		X		
	X		?		Airport	X		
	X		5		Airport	X		
	X		11	X		X		
	X		6	X		X		
Contract Hauler	X		-					
	X		-		Plant Grounds	X		
	X		?		Airport	X		
	X		5-6	X	Park	X		
	X		6-16	X		X		
		Pipeline	.07		X		Irrigation Pipe	Other Land = Diked Lagoons in Peat Bogs
	X		2-3	X		X		
	X		?	X	Park	X		Spread on Golf Courses During Winter Months
	X		5-8	X	Park	X		
	X		2-3	X	Park, Airport	X		
	X		?		Airport + Golf Course	X		

TABLE 14. (Continued)

Plant Name	Plant size, 10^3 m³/day	Type of Sewage Treatment: Primary: Mech. Cleaned	Primary: Other	Secondary: Low Rate Trickling Filter	Secondary: High Rate Trickling Filter	Secondary: Activated Sludge	Secondary: Other	No. of Years	Conduct of Landspreading Operation: Plant Personnel	Conduct of Landspreading Operation: Other	Means of Sludge Transportation: Tank Truck	Means of Sludge Transportation: Other	Distance to Site, km	Kinds of Land Used: Farm Land	Kinds of Land Used: Other
Region 5 (Cont.)															
Mankato, Minn.	22.0	X						0	X		X		6.4	X	
Minneapolis - St. Paul SD, Minn.	569			X									9.7	X	
Moorhead, Minn.	13.3			X				4	X		X		4	X	
Owatonna, Minn.	7.2			X				10	X		X		24	X	Airport
Rochester, Minn.	26.6			X				2	X		X		11.3	X	
St. Cloud, Minn.	15.7			X				15	X		X		2-3	X	
Worthington, Minn.	7.6						Not Specified	7	X		X		2-8	X	
Archbold, O.	6.8				X			2	X		X		8-16	X	
Ashtabula, O.	45.6						Chemical	7	X		X		11	X	
Belmont County S.D., O.	10.3	X						1	X		X		3.2	X	
Bowling Green, O.	18.6		X					1	X		X		3	X	
Celina, O.	7.6				X			20	X		X		3-10	X	
Conneaut, O.	6.8						Chemical	5	X		X		—		Plant Grounds
Coshocton, O.	9.5			X				4	X			Pipeline	.5	X	
Dayton, O.	182		X					40	X				16	X	
Defiance, O.	15.2						Chemical	7		Contract Hauler	X				
Delaware, O.	5.7		X								X		4.05	X	
Findlay, O.	11.4				X			14	X		X		5	X	
Green County Little Miami S.D., O.	5.7				X			8	X			X	1	X	
Greenville, O.	3.8			X				10	X		X		.5	X	
Kenton, O.	4.9				X			18	X		X		.3	X	
Lancaster, O.	38.0				X			12	X			Pipeline	.011	X	
Madison, O.	4.2						Chemical	5	X		X		3	X	
Marietta, O.	12.9						Chemical	12	X			Pipeline	.034		Plant Grounds
Marysville, O.	3.8				X			3	X		X		32	X	
Montgomery County S.D., O.	24.3				X			17	X		X		—		Plant Grounds
New Philadelphia, O.	5.7	X						1	X		X		8	X	
Norwalk, O.	10.3		X					3	X		X		24	X	Gravel Pit
Painesville, O.	11.4	X						2		Contract Hauler	X		5-10	X	
Piqua, O.	15.2				X			15		Contract Hauler	X		2-10	X	
Sidney, O.	7.6							18	X	Contract Hauler	X		16.1	X	
Springfield, O.	95			X				10	X		X		4.8		Cemetery
Steubenville, O.	34.2						Chemical	4	X		X		.2		Ir. High school
Toronto, O.	3.8	X						6	X						
Troy, O.	11.4			X				10	X		X		2	X	
Urbana, O.	5.7			X				1	X	Contract Hauler	X		2		Woodland
Van Wert, O.	3.8		X					5	X		X		16	X	
Vermilion, O.	3.8	X						4		Contract Hauler	X		6.4	X	
Wapakoneta, O.	4.8					X		14	X		X		1	X	Abandoned Landfill
Wilmington, O.	4.9					X		12	X		X		2	X	
Xenia, O.	17.1					X		13	X		X		16	X	
Zanesville, O.	38.0	X						5	X		X		11	X	Park
Baraboo, Wis.	5.3		X					15	X		X		7		Park, Golf Course
Beaver Dam, Wis.	8.4		X					24	X		X		3-10	X	
Beloit, Wis.	27.4					X		16	X		X		3-11	X	Golf Course
Burlington, Wis.	3.8		X					--	X		X		3-16	X	
Chippewa Falls, Wis.	54.0					X		25	X		X		10-13	X	
Clintonville, Wis.	3.8					X		--	X		X		6		Airport
DePere, Wis.	6.8					X		1		Contract Hauler	X		6	X	
Fort Atkinson, Wis.	5.3					X		4	X		X		8	X	
Germantown, Wis.	3.8						Extended Aeration	15	X		X		7	X	
Janesville, Wis.	13.3	X						12	X		X		2-5	X	Farm
Kaukauna, Wis.	15.2					X		7	X		X		5	X	
Manitowoc, Wis.	36.9			X				7	X		X		4	X	
Menomonie, Wis.	4.6			X				1	X		X		2-5	X	
Monroe, Wis.	5.7					X		3	X		X		2-8	X	Airport + Football Field
New London, Wis.	4.6							4	X		X		5	X	
Oshkosh, Wis.	45.6						Chemical	43	X		X		11	X	
Portage, Wis.	4.9			X				10	X		X		6	X	Park, Airport
Prairie Du Chien, Wis.	3.8	X						13	X		X		5	X	
Reedsburg, Wis.	3.8			X				30	X		X		1	X	Airport
Shawno, Wis.	4.2			X				--	X		X		1	X	
Sparta, Wis.	4.2			X				3	X		X		8		Park, Airport
Stevens Point, Wis.	6.5					X		33		X	X		—		Park
Sun Prairie, Wis.	3.8						Flash Aeration	7	X		X		2	X	Park
Tomah, Wis.	4.6					X		14	X		X		5	X	
Watertown, Wis.	8.5				X			19	X		X		2-16	X	
West Bend, Wis.	8.5					X		5	X		X		18	X	
Wisconsin Rapids, Wis.	12.9						Chemical	3	X		X		—		Airport

TABLE 14. (Continued)

Operation	Means of Sludge Transportation			Kinds of Land Used		Kinds of Spreading Equipment		Comments
Other	Tank Truck	Other	Distance to Site, km	Farm Land	Other	Tank Truck	Other	
	X		6.4	X		X		Presently Only on a Trial Basis
	X		9.7	X		X		
	X		6	X		X		
	X		24	X	Airport	X		
	X		11.3	X		X		Tank Truck is a 19.9-m^3 Tractor-Trailer Unit
	X		2-3	X		X		
	X		2-8	X		X		
	X		8-16	X		X		
	X		11	X		X		
	X		2.2	X		X		
	X		3	X		X		
	X		6-16	X		X		
	X		--		Plant Grounds	X		
		Pipeline	.5	X			X	Other Application Means = Sludge is Lagooned Then Pumped to Adjoining Land
Contract Hauler	X		16	X		X		90-hectare Underdrained Field With Underdrainage to River. Cattle are Grazed on the Field
	X		6.05	X		X		
	X		5	X		X		
		X	1	X			X	Other Transportation and Application Means = Tractor Towed Liquid Manure Tank
	X		.3	X		X		
	X		.3	X		X		32 hectares of City-Owned Land Adjacent to Plant. Field Corn Raised Under Agreement With Local Farmer
		Pipeline	.611	X			Irrigation Pipe	
	X		5	X		X		
		Pipeline	.094		Plant Grounds		Irrigation Pipe	
	X		32	X		X		Have Hauled to Sod Fields With Great Success
	X		--		Plant Grounds	X		
	X		8	X		X		
Contract Hauler	X		24	X	Gravel Pit	X		
Contract Hauler	X		8-10	X		X		
Contract Hauler	X		2-10	X		X		Tried Subsoil Injection but was (1) Too Slow, (2) Injectors Would Jump Out of Ground, and (3) Couldn't Use When Ground was Frozen
	X		16.1	X		X		
	X		4.8		Cemetery	X		
	X		.2		Jr. High school	X		
	X		2	X		X		
Contract Hauler	X		2		Woodland	X		
	X		16	X		X		
Contract Hauler	X		6.4	X		X		
	X		1	X	Abandoned Landfill	X		
	X		8	X		X		
	X		16	X		X		Tank Truck is a 11.4-m^3 Tractor-Trailer Unit
	X		11	X	Park	X		Other Land = Abandoned Landfill, Airport, Plant Grounds, Vacant Field Adjacent to Plant
	X		9		Park, Golf Course	X		
	X		8-10	X		X		
	X		8-11	X	Golf Course	X		
	X		3-16	X		X		
	X		10-13	X		X		Presently Lease 32.4 hectares of Land and Plan to Purchase a 81-hectare Farm for Liquid-Sludge Disposal
	X		6		Airport	X		
Contract Hauler	X		6	X		X		
	X		8	X		X		
	X		2	X		X		
	X		3-5	X	Park	X		
	X		5	X		X		
	X		8	X		X		24-hectare Field Owned by City
	X		2-5	X		X		
	X		2-8	X	Airport + Football Field	X		
	X		5	X		X		
	X		11	X		X		
	X		6	X	Park, Airport	X		
	X		5	X		X		
	X		1	X	Airport	X		
	X		1	X		X		
	X		8		Park, Airport	X		
X	Y		--		Park			City Parks Department Sprays Sludge on Parks in Late Fall Before Snows Arrive
	X		2	X	Park	X		
	X		8	X		X		
	X		2-16	X		X		
	X		10	X		X		
	X		--		Airport	X		

TABLE 14. (Continued)

Plant Name	Plant Size 10^3 m^3/day	Type of Sewage Treatment: Primary: Much Cleaned	Primary: Other	Secondary: Low Rate Trickling Filter	Secondary: High Rate Trickling Filter	Secondary: Activated Sludge	Secondary: Other	No. of Years	Conduct of Landspreading Operation: Plant Personnel	Conduct of Landspreading Operation: Other	Means of Sludge Transportation: Tank Truck	Means of Sludge Transportation: Other	Means of Sludge Transportation: Distance to Site, km	Kinds of Land Used: Farm Land	Kinds of Land Used: Other
Region 9															
Bakersfield, Calif.	79.9						Land Application	15	X			Pipeline	.6	X	
Colton, Calif.	19					X		29	X			Pipeline	1	X	Pasture Land
Irvine, Calif.	7.6					X		5	X			Pipeline	.2	X	
Kennan, Calif.	3.9						Land Application	20	X			Pipeline	1	X	
Lindsay, Calif.	4.6						Stabilization Pond	3	X		X		-	X	Meyerink
Lodi, Calif.	20.5					X		4	X			Pipeline	6	X	
Los Angeles S.D. #20, Calif.	39					X		9		Contract Hauler	X		11	X	
Oceanside, Calif.	7.2						Stabilization Pond	2	X		X		5		Canyon Landfill
Petaluma, Calif.	11.4					X		3	X			Pipeline	.2		Open Field
San Juan Capistrano, Calif.	3.8					X		1	X		X		11		
San Leandro, Calif.	58.0					X		5	X	X	X	Pipeline	8	X	
Santa Barbara, Calif.	30.4	X						1	X		X		32		X
Reno - Sparks, Nev.	76					X		--		X	X		-	X	
Winnemucca, Nev.	3.8						Extended Aeration	7	X			X	-		Golf Course
														X	

TABLE 14. (Continued)

Landspreading Operation	Means of Sludge Transportation			Kinds of Land Used		Kinds of Spreading Equipment		
Other	Tank Truck	Other	Distance to Site, km	Farm Land	Other	Tank Truck	Other	Comments
		Pipeline	.8	X			Irrigation Pipe	
		Pipeline	1	X	Pasture Land		Irrigation Pipe	
		Pipeline	.2	X			Irrigation Pipe	
		Pipeline	1	X			Irrigation Pipe	
	X		-	X	Stripmine		Irrigation Pipe	Sludge is Mixed With Effluent Sludge is Disked in After Drying
		Pipeline	0	X			Irrigation Pipe	
Contract Hauler	X		11	X		X		
	X		5		Canyon Landfill	X		
		Pipeline	.2		Open		Irrigation Pipe	
	X		11		Field			
X	X	Pipeline	8	X		X		
	X		92		X	X		Highway Dept., Uses 38.7 m^3/Day. Sludge is Also Spread Around Plant Grounds Via Pipeline
X	X		-	X		X		
					Golf Course	X		
		X	-					
				X			Open Irrigation Ditch	

Some operations are being conducted on a trial basis, while other sewage treatment plants have utilized landspreading longer than 40 years. Data gathered via the survey reveals that landspreading is indeed growing in popularity and utilization. An examination of the survey responses, which included the number of years that landspreading has been practiced by the various sewage treatment plants, reveals that 68 percent of the plants responding have been conducting landspreading for less than 10 years. Of this 68 percent, over two-thirds have begun the practice only within the last 5 years.

Tank trucks are the predominant method of spreading liquid sewage sludge. Other spreading methods utilized are pipe, spray and sprinkler irrigation. Sub-sod plow-down injection and ridge and furrow methods are also utilized.

The survey indicates that the lands utilized for landspreading are predominantly agricultural. Parks, airports, golf courses, abandoned landfills, and strip mines, among others, are also utilized. In one case--San Leandro, California--about 3.8 x 10^3 m^3/day of liquid sewage sludge is spread by the Highway Department on median strips.

FIELD VISITS

The purpose of the field visits was to attempt to obtain pertinent unreported data relative to landspreading and to prepare case history write-ups based upon observations of the operations and interviews with the plant personnel. The types of data deemed most pertinent to the landspreading operations included the type and amount of land used, the kind of waste water treatment employed, the quantity and quality of sludge, the type of sludge stabilization used, the conveyance system, distance to the site, sludge application rates, soil and crop response, and the costs of disposal.

Accordingly, 26 plants in six states were selected for visitation as follows:

		Number of plants visited	
State	Region	3.8-38 X10^3 m^3/day	3.8-38 X10^3 m^3/day
California	9	3	2
Florida	4	3	1
Illinois	5	-	1
Minnesota	5	5	-
Ohio	5	3	3
Wisconsin	5	4	1

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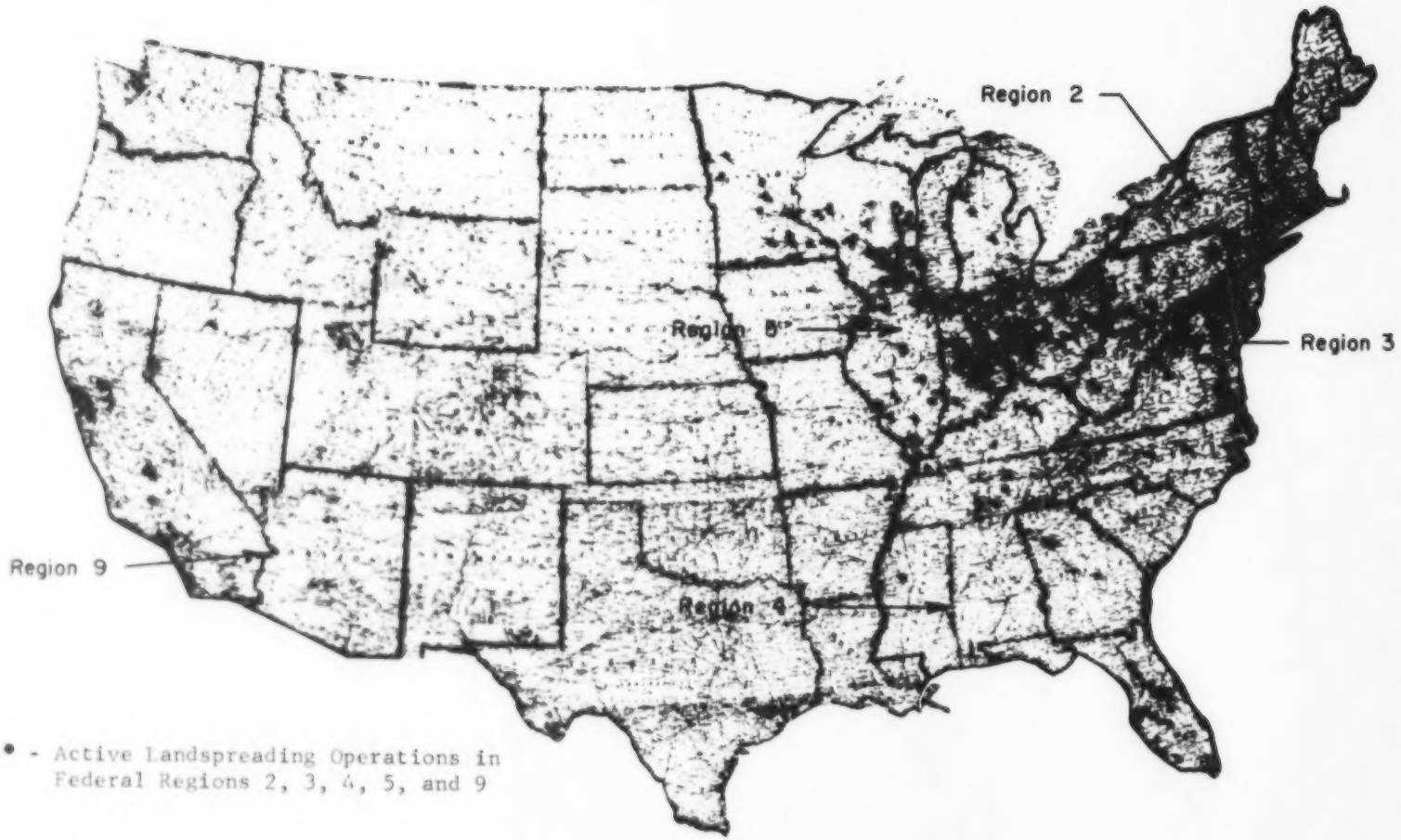

FIGURE 4. DISTRIBUTION OF SEWAGE TREATMENT PLANTS USING LANDSPREADING ON A ROUTINE BASIS

These states and plants were considered representative of the extremes of population, climate, topography, and soils which would be encountered throughout the five Federal Regions of interest to this study.

The following discussion provides an overview of the information obtained during the plant visits and also presents some conclusions drawn from observation of the various operations and interviews with plant personnel. The first conclusion drawn from these visits is that plant economics are the primary driving forces behind most decisions to utilize landspreading. Those aspects of landspreading that offer a more trouble-free operation are also involved, but, nevertheless, economics remains the prime mover even though detailed cost figures were not always available to substantiate this fact. The often repeated benefits of liquid sludge (i.e. - fertilizer value, soil conditioning, source of supplemental water, etc.) were reiterated by most plant operators, but, again, there was essentially no data beyond empirical judgments to add credence to these claims.

Generally speaking, information was readily available on such operational aspects as the type of influent (i.e. - percent domestic vs percent industrial), the type of wastewater treatment used, the quantity of sludge disposed of, the conveyance system used, distance to landspreading site(s), the type(s) of land used, and the methods of obtaining land. However, data relative to the most significant aspects of the operation - i.e., the amount of land and sludge application rates used, crop and soil response, and the costs of disposal - were generally lacking or, at best, incomplete.

The normal practice is to have a number of sites available for utilization in order to rotate sludge applications and to assure continuity of the operation during adverse weather conditions. However, sufficient records are not kept at most treatment plants to enable a determination of the loading rate at which sludge is applied to the individual sites. As a rule, the records show only the total amount of sludge taken from the plant.

In most instances, soil and/or crop response was reported to be good. However, this is based primarily on observation alone, as only two of the plants visited (Springfield, Illinois, and Moorhead, Minnesota) have conducted studies along these lines. Most plant operators indicated that such information is not solicited from the farmers who are receiving the sludge.

As discussed in a previous section of this report, the quality of the sludges should be an important consideration in the planning and design of a landspreading operation. However, no extensive sludge analyses were encountered beyond those required for plant operation or by the various state agencies -- specifically, total dissolved solids, volatile solids, and pH.

Accurate operational costs for sludge disposal were difficult to obtain, as many of the plants visited did not maintain separate records for the cost of sludge disposal. For instance, labor is an important function in determining the cost of the sludge disposal operation. In many instances, the personnel who conduct the sludge disposal operation also serve in other capacities around the plant. It was not a normal practice to record separately the amount of time an individual devoted to sludge disposal. The available cost estimates obtained from the plants visited are presented in Table 15.

As a whole, the plant personnel interviewed were relatively pleased with their landspreading operations and reported no major problems or complaints. Although accurate cost recording was not the rule, most were convinced of the economics of landspreading when compared with alternative means of sludge disposal - i.e. vacuum filters, centrifuges, sand-drying beds, etc. In fact, numerous idle vacuum filters and abandoned sand-drying beds were noticed during the plant visits. Also, several of the plants were either undergoing expansion and upgrading at the time of visitation, or were awaiting funds for expansion and upgrading. More often than not, the plans called for a continuation of the landspreading operation under the new scheme.

Case History Write-Ups

California Plants

Bakersfield - The digested sludge containing 5 percent total solids (50 percent volatile) is pumped to a 2.4-hectare, 3-meter-deep ditch 0.4 kilometers from the plant. Occasionally, some of the sludge is mixed with plant effluent and used for irrigation of adjacent grass and farmland. The average monthly sludge output is about 303 m^3. No other data were available.

Oceanside - Sludge from the anaerobic digester containing 5 percent total solids is currently being dumped into a plastic film-lined canyon 3 kilometers from the plant. This is being done as part of an experimental program sponsored by EPA to study, among other things, the leachate characteristics from a bed comprised of alternate layers of trash (garbage) and sewage sludge.

The plant operation produces two to four 11.4-m^3 truckloads every week. The canyon landfill has caused some occasional nuisance odors, apparently because of insufficient time of retention of sludge in the digester. The canyon is close to a public school and some industrial plants.

Prior to disposing of the liquid sludge in this canyon landfill, the sludges were disposed of in 1-meter-deep ditches. However, under the orders of the Water Quality Control Board of San Diego County, this practice was discontinued since the water table was only 1.5 meters below grade.

Table 15. ESTIMATED OPERATING COSTS OF SELECTED LANDSPREADING OPERATIONS

	sludge hauled 10^3 m^3	% Solids	Dry tons	Labor cost	Fuel cost	Maint. cost	Deprec. cost	Other cost	Total cost	$/$m^3$	$/ dry ton	Comments
Defiance, Ohio	7.87	6.0	471	-	-	-	-		13,520	1.72	28.66	Contract hauler.
Sidney, Ohio	34.1	3.5	1,192	9,240	1,725	-	-		10,965	.32	9.19	
Zanesville, Ohio 1969	5.34	10.0	584	1,753	133	362	-		2,248	.39	3.85	
1970	5.39	13.0	700	1,170	168	457	-		1,795	.33	2.57	
1971	5.67	12.4	702	1,430	230	360	-		2,020	.36	2.88	
1972	4.78	12.4	592	1,436	221	331	-		1,988	.42	3.35	
Springfield, Ohio	6.23	8.6	535	3,014	134	600	1,096		4,844	.58	9.05	
Xenia, Ohio 1971	8.69	3.5	304	7,696	236	271	2,400		10,603	1.22	34.89	
1972	15.70	3.5	550	6,698	442	1,304	2,400		10,843	.69	19.72	
DePere, Wisconsin	16.14	3.75	605	-	-	-	-		17,056	1.06	28.19	Contract hauler.
Kaukauna, Wisconsin	1.59	5.6	89	1,251	187	696	-		2,134	1.34	24.01	
Oshkosh, Wisconsin	4.17	5.9	246	-	-	-	-		16,537	3.96	67.26	Data for May, 1973. Contract hauler.
Beaver Dam, Wisconsin	3.91	6.4	250	2,077	-	-	-	1,707	3,784	.97	15.11	Other cost - truck rental from City Motor Pool
Moorhead, Minnesota Sept., 1972	3.44	1.84	64	721	93	125	242	140	1,321	.38	20.80	Other cost - insurance ($114), interest ($26)
Oct.,1972	3.59	1.44	52	724	118	125	242	140	1,349	.38	26.09	Other cost - insurance ($114), interest ($26)
Segus, California	31.49	3.0	944	-	-	-	-		60,580	1.92	64.14	Total cost - $53,300 for truck & driver + $7,280 paid to farmer
Santa Barbara, California	32.95	5.0	1,598	-	-	-	-		293,400	9.17	183.63	Total cost - $230,000 for truck expense + $63,400 paid to farmer

San Juan Capistrano - The sludge produced in the anaerobic digesters of the 8.7 x 10^3 m^3/day plant together with that generated in the activated sludge units is first thickened in a flotation thickener and then sent through two continuous solid bowl Bird centifuges. The resulting sludge containing 29 percent total solids is transported to an elevated hopper using a series of belt conveyers. The sludge accumulated in the hopper is spread over a 0.2 hectare plot adjacent to the plant. Approximately 23 m^3 of sludge are accumulated daily.

This plant faces problems in disposing of its sludge. Spreading of thinner sludge (about 5 percent total solids) was done on grassland 11 kilometers from the plant using a tank truck. This operation was discontinued, however, as a result of an order by the Orange County Health Department. Apparently, the grassland was located on a flood-plain. For some time after the discontinuation of the spreading operation, the thin sludge was hauled to a nearby plant where sludge thickening and incineration facilities were available. The plant operator is now in the process of working out an agreement with a private contractor, whereby the 20 percent sludge will be rmoved from the plant site for later processing to produce a rich topsoil. The tentative cost of the latter operation was put at \$7.65/m^3.

Santa Barbara - The anaerobically digested sludge from this 38 x $10^3 m^3$/day plant contains 5 percent total solids (70 percent volatiles) and is currently being hauled 92 kilometers to a private farm. Prior to the application of liquid sludge, the land is disced and after several sludge applications it is rotary tilled. The high sodium and chloride contents in the liquid portion of the sludge preclude its use to irrigate fruit crops. The cost of transporting 32.0 x 10^3 m^3 (1,598 dry tons) of sludge produced per year is reported to be about \$230,000. Additionally, the sum of \$45 per 22.7 m^3 truckload (\$63,400 per year) is paid to the owner of the farmland, bringing the total cost of the operation to about \$293,400 per year. This amounts to disposal costs of \$183.63/dry ton (\$9.17/m^3).

Saugus (Los Angeles County District 26) - Liquid sludge from this 11.4 x 10^3 m^3/day plant's anaerobic digesters averaging 3 percent solids (65 percent volatile) and pH of 7.0 is hauled away by a private contractor to a farm located 16.1 kilometers from the plant. A 15.1 m^3 tank-trailer truck is used to transport eight loads over a period of 10 hours per day 5 days per week. The truck (with driver) is rented for \$20.50/hour. In addition, the farmer is paid \$3.50/truckload for preparing the land prior to sludge spreading (i.e., discing to a depth of 15 cm).

The land to which sludge is applied on a rotating basis is used to grow mainly corn and melons. Prior to planting, the land is rotary tilled to a depth of 45.7 cm. The total land area receiving regular applications of liquid sludge is about 24.3 hectares. Plant personnel reported that application of liquid sludge to the cultivated land has reduced nitrogen fertilizer requirements by one-half.

Using the above data, costs for the operation are estimated to be $64.22/ton and $1.92/$m^3$.

Soil and crop response were reportedly good, but no data were available to quantify this observation. No environmental monitoring is conducted.

Florida Plants

Ocala - Landspreading of anaerobically digested sludge averaging about 8.9 percent solids (40-45 percent volatile) with a pH value of 7.3 has been practiced at this 13.2 x 10^3 m^3/day plant for the past 15 years. The sewage influent is composed of approximately 90 percent domestic wastes and 10 percent industrial wastes from a citrus processing plant and a slaughterhouse. The sludges are produced for digestion by plain sedimentation and trickling filters. Prior to the initiation of the landspreading operation, vacuum filters were used to dewater the sludge and the dried product was spread on the land.

Two tank trucks (7.57 m^3 and 11.4 m^3 capacities) are used to haul and spread the liquid sludge on privately owned pastureland within 19-21 kilometers of the plant. The hauling operation consists of six trips per day five days per week throughout the year.

In most cases, local farmers have requested that liquid sludge be spread on their pastures after observing the results of sludge applications on other farms. When sludge is requested in a new area, the plant personnel will contact the neighboring landowners and explain the nature of the operation. In general, public reaction to the landspreading operation has been favorable, with only an occasional complaint regarding odors.

Cattle are normally left in the fields during the landspreading operation; however, they will avoid the sludged areas for some 3-5 days after spreading. Pasture response to the liquid sludge is apparently good and application rates were estimated to be on the order of 74.8 m^3/hectare. At these application rates, no crust formation has been noted.

Environmental response monitoring is not conducted nor are operational costs maintained separately from other plant operating costs.

St. Petersburg - Anaerobically digested sludges averaging about 2.5 percent solids (70 percent volatile) and a pH of about 7.1 have been disposed of via landspreading for the past 2 years. Four sewage treatment plants (two primary and two activated sludge plants) treat essentially 100 percent domestic sewage. The sludges are produced for anaerobic digestion by primary and secondary (activated) sedimentation. Essentially all the sludge disposed of via landspreading comes from the two activated sludge plants (109 x 10^3 m^3/day).

Conventional sand-drying beds had been used to dewater the sludges, however, when the plants were converted to activated sludge systems, problems were encountered in dewatering the sludges on the sand beds. Consequently, the decision was made to utilize a combination lagoon/landfill and landspreading for the disposal of liquid digested sludge.

The initial attempt at landspreading involved ridge and furrow application to a field adjacent to the Southwest Plant grounds. The minimum cost estimates for this method were reported to be $38.60/ton and required a minimum of 8 hours to treat 0.4 hectare of ground. This method was thus abandoned due to its high cost of operation, and a 10.9 m^3 tank truck (diesel) was purchased to haul and spread the liquid sludge. A pressurized line running from the digester to the sand beds was tapped and a valve arrangement installed for loading the truck. Sludge discharge from the truck is by gravity flow, and a spreader bar assures an even distribution of the sludge.

On the average, some 1.8×10^3 m^3 of liquid sludge are disposed of each month via the following scheme. Approximately 20 percent of the liquid digested sludge is disposed of via landspreading. The remaining 80 percent is hauled to a city-owned lagoon/landfill operation by a 30 m^3 tractor-trailer unit.

Presently, all of the liquid digested sludge disposed of through landspreading is being used to build up the extremely sandy soils for planned golf courses and park areas. Application rates were estimated to be on the order of 28 m^3/ha. Although no problems were reported regarding the landspreading operation, the plant personnel speculated that the "human waste stigma" might hamper a more widespread adoption of landspreading.

No environmental response monitoring is conducted nor are data routinely kept on the costs of sludge disposal via landspreading. The tank truck, however, was purchased new in 1972 at a cost of $33,000 and has since logged some 25,740 kilometers hauling liquid sludge. During the periods when sludge is being hauled an average of 143 m^3/day are disposed of via landspreading on sites within 8 kilometers of the plant site.

Tallahassee - Anaerobically digested sludges averaging about 4.5 percent solids (55-60 percent volatile) from three activated sludge sewage treatment plants (30.3×10^3 m^3/day total) have been disposed of via landspreading for the past 14 years. The influent sewage is essentially composed of 95 percent domestic wastes and the sludges are produced for digestion by plain sedimentation and both low-rate and high-rate trickling filters. Sand drying beds were used to dewater the sludge before landspreading was adopted.

Presently, city-owned land surrounding the airport is being used for the landspreading operation. Some 810 hectares of land are available at this site, but only 85 hectares are currently used for landspreading. The soils of the area are extremely sandy and were reported to be approximately 12.2 meters deep. Two tank trucks (9.08 and 15.5 m^3 capacities) are used to haul and spread the sludge.

Good grass growth is being maintained on the sandy soils and the plant management is considering growing hay on the site for harvest and subsequent sale to local farmers. About 1,562 tons of sludge solids have been spread at the site over the past 8 months. However, the amount of land over which this was spread was not known, so application rates could not be determined. Plant personnel indicated they attempted to obtain application rates of approximately 56 tons/ha/year.

Operation and maintenance costs for the trucks were reported to be on the order of $0.10/kilometer.

While the operators considered landspreading to be the best available and most economical means of sludge disposal, the operation is presently being conducted under a temporary State permit until another means of disposal is selected. Tentative plans are to dewater the sludge in a centrifuge to 10 percent solids and then dispose of it in a landfill.

Winter Park - The sewage entering this 17 x 10^3 m^3/day activated sludge plant is composed of essentially 100 percent domestic wastes. The sludges produced by plain sedimentation are anaerobically digested and normally range from 1.3-1.5 percent solids (77 percent volatile). Land disposal of liquid sludge has been practiced here for 5 years. Prior to landspreading, sand beds were used to dewater the liquid sludge. The beds were abandoned when sludge volumes became too great for the beds to handle in rainy weather.

With the decision to use landspreading, two 9.5-m^3 tank trucks (diesels) were purchased. These, however, are not tank trucks in the normal sense of the word. Rather, they are dump trucks which have been modified to serve as tank trucks. The modification included the installation of gasketed covers on the beds, leak proofing the beds,and installation of a spreader bar and discharge-valve arrangement. Loading of the truck is by gravity flow directly from the digester. Sludge discharge is by gravity flow. In the event that the landspreading operation would be discontinued, very little work would be required to restore the original dump truck configuration. Each truck is equipped with high flotation tires to facilitate movement in the area's sandy soils.

An interesting situation was encountered at this plant relative to hauling sludge across county lines. Winter Park is located in Orange County near the Seminole County line. The initial landspreading operation was conducted on somewhat poor pastureland in Seminole County not far from the Winter Park plant. With the increased grass growth promoted

by the liquid sludge, the rancher was able to substantially increase the number of cattle grazed on this land. For some unexplained reason, Seminole County officials elected to halt the hauling of sludge into their County. Legal action taken by the ranch owner was to no avail, and since the landspreading activity was discontinued, the rancher's herd has reportedly decreased in number by approximately three-fourths.

With the loss of this convenient site, the plant management approached a local orange grove owner and obtained his permission to apply the liquid digested sludge to an extremely large grove located about 22 kilometers from the plant. The landspreading operation is now conducted 5-7 days/week throughout the entire year. The liquid sludge dries rapidly on the sandy soils (reported to vary between 0.6-3.0 meters in depth), and posttreatment of the site in the form of discing is conducted by the grove owner.

No pre- or postoperational monitoring of soil or crop response is conducted, and a sludge analysis beyond that mentioned above was not available. Also, operational costs and sludge application rates were not recorded.

Illinois Plants

Springfield - (The following description of the Springfield landspreading operation is an abstract of a soon-to-be-published paper by A. P. Troemper, Executive Director, Springfield Sanitary District. The abstract aptly summarizes the Springfield activated secondary sewage treatment operation and is included herein with the permission of Mr. Troemper.) Since 1965 the Springfield Sanitary District has been expermenting with disposal of liquid anaerobically digested sludge by irrigation of agricultural land. A 2.8-hectare test plot of poor cropland was utilized for this purpose. Certain conclusions were possible as a result of these studies: (1) while considerable variation (due to climatic conditions) in results may be expected from one year to another, the disposal method is economically feasible, (2) sludge should be applied to land utilized for growing crops rather than uncropped land, (3) soil moisture is a great limiting factor in this method of sludge disposal, (4) while application of sludge to the land by flooding is possible, this method results in numerous problems (spray application seems more desirable), (5) crops utilized on the disposal area should have a high demand for N and P, and (6) storing of sludge in lagoons for later distribution has not proven practical.

During 5 years of this period for which good records are available, an average of 51.6 tons of dry solids equivalent were applied per acre each year. Corn was grown on the test plot as well as on an adjacent area used for comparative purposes. No fertilizer was used other than sewage sludge. Average production on the test plot was 7.13 m^3 per hectare (81.9 bushels per acre) and on the adjacent land 57.5, or an increase in

yield of 42 percent (Table 16). An economic analysis was made based on the increased yield as opposed to the costs of land plus improvements. The difference, considered to be the cost of sludge disposal, averaged $2.71 per ton of dry solids.

Based on results obtained, the Sanitary District is constructing a disposal area to handle all of the anaerobically digested sludge at the existing treatment works and is also constructing a similar area to dispose of all aerobically digested sludge at a new treatment works. Both of these developments will provide for screening or comminution of the sludge, permanent pumping facilities, permanent distribution facilities to allow spraying the sludge during the entire year, and an underdrainage system to collect and return the leachate to the treatment plant. Each area is about 14.2 hectares in size. Development costs of the areas are presented in Tables 17 and 18. It is anticipated that the future disposal cost will approximate the cost of disposal during the experiment.

Minnesota Plants

Anoka - The Anoka Wastewater Treatment Plant is a 9.5×10^3 m^3/day plant and is part of the Metropolitan Sewer Board of the Twin Cities Area. The treatment given the wastewater consists of (1) screening, (2) grit removal, (3) primary sedimentation, (4) conventional activated sludge with contact stabilization, (5) secondary sedimentation, and (6) aerobic digestion. Currently, the liquid sludge is hauled to a large drying bed at the city landfill and dewatered. Eventually, the dried sludge will be bulldozed out of the beds and used to reclaim low-value land.

They practiced landspreading of liquid sludge for 13 years, but discontinued the operation. Though they had no problem with the operation, they changed from landspreading to drying beds when the management of the treatment plant changed. The City of Anoka originally built the plant, but it was sold to the Metropolitan Sewer Board (7 counties around the Twin Cities area). At this time, the plant was changed from a trickling filter to an activated sludge plant and the sludge volume doubled, i.e., the sludge composition went from 7 percent to 3.5 solids. The plant superintendent believes that it is less expensive to operate the drying beds than the landspreading operation with the present system.

They formerly used a 3.8-m^3 tank truck to spread the liquid sludge on a golf course. The operation was fairly satisfactory with few complaints. With the increase in liquid sludge volume, they would have had to purchase a 15.1-m^3 tank truck and increase their storage capacity. Studies were made by the plant personnel and it was concluded that drying beds would be more economical.

Detroit Lakes - The Detroit Lakes Wastewater Treatment Plant is a 3.8 to 4.9×10^3 m^3/day plant that treats 100 percent domestic sewage. The primary and secondary sludges produced by sedimentation and high-rate

Table 16. TABULATION OF CROP YIELDS AND SLUDGE APPLICATION AT SPRINGFIELD, ILLINOIS [44]
(Presented in English Units.)

Crop year	Crop yield, bu/acre: Sludge irr. area	Crop yield, bu/acre: No liquid sludge area	Increase crop yield bu/acre	Net $ yield per acre	Corn price, $/bu	Increased $ yield per acre of liquid sludge area over other	Actual acres planted	Sludge applied: Thousand gallons	Sludge applied: Tons D.S. per acre	Cost per ton of dry sol.
1965	107	88	19	$65.19	$0.95	$18.05	7	3,415	106	$0.97
1966	76	39	37	49.02	1.19	44.03	7	2,360	67	1.77
1967 [a]	--	--	--	20.00	--	--	0	290	11 [b]	17.05
1968	62	32.5	29.5	7.07 [b]	0.897	26.46	4	1,105	36 [b]	4.46
1969	82.6	70.5	12.1	9.86 [b]	0.954	11.54	2.9	--	--	--
1970	--	--	--	--	--	--	--	--	--	--
1971	--	--	--	--	--	--	0	2,260	64	2.62
Avg. [c]	81.9	57.5	24.4	$22.23	$0.998	$25.02	5.2	1,886	56.8	$2.46

[a] Terraces tiled at the cost of $8,005.73.

[b] Based on 7 acres.

[c] Excludes 1967 data in average.

Table 17. DEVELOPMENT COSTS OF SUGAR CREEK SLUDGE DISPOSAL AREA AT SPRINGFIELD, ILLINOIS [44] (BID PRICES OF LOW BIDDERS ON PROJECT)
(Presented in English Units)

Pumping station		
Structure (est. 1/3 of $94,932)	$31,644.00	
Equipment (est. 1/3 of $36,072)	12,026.00	
Sludge comminutor	6,352.00	
Total pumping station		$ 50,022.00
Sludge distribution		
1,820 of 8 in. C.I. force main at $9.90	18,018.00	
5,735 ft of 6 in. C.I. force main at $7.05	40,431.75	
8 in. valves - 8 at $250	2,000.00	
6 in. valves - 44 at $175	7,700.00	
Fittings - 9,415 lb at $0.60	5,649.00	
Spray nozzles - 6 at $440	2,640.00	
Total sludge distribution system		76,438.75
Disposal area underdrainage		
23,610 ft of 4 in. perforated PVC pipe at $2.00	47,220.00	
1,300 ft of 6 in. perforated PVC pipe at $2.64	3,432.00	
640 ft of 8 in. perforated PVC pipe at $4.00	2,560.00	
Underdrainage pump pit & controls	6,593.00	
Total underdrainage system		59,805.00
Miscellaneous		
4,000 ft of woven wire stock fence at $2.00	8,000.00	
Electrical (1/20 of $253,700 - total plant elect. bid)	12,685.00	
Total miscellaneous		20,685.00
Total development cost (exclusive of land)		$206,950.75
$\frac{\$206,950.75}{35.73}$ = $5,792.07 per acre development cost of disposal area		
Land cost		
2,075 ft x 750 ft = 35.73 acres		
35.73 at $750 per acre land cost =		26,797.50
Total disposal area cost		$233,748.25
$\frac{\$233,748.25}{35.73}$ = $6,542.07 per acre total cost of disposal area		

Table 18. DEVELOPMENT COSTS OF SPRING CREEK SLUDGE DISPOSAL AREA AT SPRINGFIELD, ILLINOIS [44] (BID PRICES OF LOW BIDDERS ON PROJECT)
(Presented in English Units)

Screening and pumping of sludge		
Structure	$ 6,275.00	
Equipment	15,768.00	
Total screening and pumping		$ 22,043.00
Sludge distribution		
6,456 ft 6 in. C.I. force main at $3.25	20,962.50	
900 ft underdrain return at $8.56	7,704.00	
25 spray irrigation headers and risers at $321.00	8,025.00	
2 spray nozzles at $496.00	992.00	
Total sludge distribution system		37,683.50
Disposal area underdrainage		
35,500 ft 4 in. perf. PVC pipe at $2.50	88,750.00	
1,300 ft 6 in. perf. PVC pipe at $3.25	4,225.00	
2,475 ft 12 in. perf. PVC pipe at $8.30	20,542.50	
Underdrain lift station	2,657.00	
Underdrain lift station equipment	8,294.00	
Total underdrainage system		124,468.50
Miscellaneous		
Pipe and foot bridge relocation	10,523.00	
Revision and adjustment of bridge	365.00	
Pipe supports and braces on bridge	1,340.00	
Electrical (1/20 of $134,939 - total plant elect. bid)	6,746.95	
Total miscellaneous		18,974.95
Total development cost (exclusive of land)		$203,169.95
$\frac{\$203,169.95}{30}$ = $6,772.33 per acre development cost of disposal area		
Land cost		
20 acres at $459.96 per acre		9,199.20
10 acres at $500.00 per acre		5,000.00
Total land cost		14,199.20
Total disposal area cost		$217,369.15
$\frac{\$203,169.95 + 14,199.20}{30}$ = $7,245.63 per acre total cost of disposal area		

trickling filters are anaerobically digested and sent to peat bog lagoons. There are numerous peat bogs in the area, and the City of Detroit Lakes uses these for sludge disposal. In the operation they dig the bog out and use the soil as fill for the side banks on the lagoon. As the lagoon fills and drys out, grass and trees grow. They then shift to a new peat lagoon. Eventually, the lagoon returns to meadowland.

Fergus Falls - The Fergus Falls Wastewater Treatment Plant is a 7.9 x 10^3 m^3/day plant that treats about 6.1 x 10^3 m^3/day (76 percent) domestic sewage and 1.9 x 10^3 m^3/day (24 percent) industrial sewage. The sludges produced by sedimentation and high-rate trickling filters are anaerobically digested. Normally, the solids content of the digested sludge is about 3.5 percent.

At one time, the sludges were dewatered on drying beds; however, these were removed in 1959. Since that time all of the digested sludge has been spread on farm fields and a city-owned golf course. The sludge is spread on the golf course in the winter and the farm in summer.

The secondary digester acts as the holding tank for the sludge prior to withdrawal for landspreading. An 8.3-m^3 tank truck is used to haul and spread the sludge. Normally, 6 loads per day are hauled by one full-time operator. In the summer the sludge is applied to about 18.2 hectares, 8.1 hectares of pasture, and 10.1 hectares that are planted in corn the following year. The application is made on alternate years on the pastureland and the cornfield. The distance to the golf course is 11 to 13 kilometers and 10 to 11 kilometers to the farm. A rough cost estimate was supplied by the plant superintendent as follows:

Labor = \$540/mo

$$\text{Dry tons} = 45.4\ m^3/\text{day} \times 21.75\ \frac{\text{days}}{\text{mo}} \times .035 \times \frac{\text{ton}}{m^3} = 34.6\ \text{dry tons/mo}$$

Labor ≈ 1/2 total cost

$$\$/\text{ton} = \frac{2 \times \$540/\text{mo}}{34.6\ \text{tons/mo}} \approx \$31.00/\text{ton dry solids.}$$

The farmer plows and discs the soil at no expense to the plant. The plant superintendent is satisfied with the operation. They have had no major problems or complaints, although they have had some odor problems.

An interview was held with the local farmer regarding his feeling about the operation. He indicated that the best results were obtained on grass and hay. He could not notice any difference in his corn yield. There are no odors except at the time of spreading. His main complaint is that 6 to 8 applications are required to fertilize the soil and the trucks pack the ground so that it is difficult to plow.

Moorhead - The Moorhead Wastewater Treatment Plant is a 17 x 10^3 m^3/day activated sludge plant that treats about 11.4 x 10^3 m^3/day of domestic wastewater. The only industry in the area is a creamery that contributes about .38 x 10^3 m^3/day. Primary and secondary sludges produced by sedimentation and high-rate trickling filters are anaerobically digested (15 days at 35 C) and held in an unheated secondary digester for ultimate disposal to the land.

The anaerobically digested sludge, containing about 2 percent solids, is hauled by two tank trucks to a 130-hectare city-owned farm which is rented to a farmer. The land is used for small grain farming and the usual crops are winter wheat and barley with some soybeans and sugarbeets.

One truck, a 1972 model, can haul 13.2 m^3 while an older truck, a 1966 model, can haul 11.4 m^3. Each truck is equipped with a specially designed spray bar so that the sludge is distributed equally over an 8-foot wide path as the truck moves slowly through the field.

The land to which the sludge is applied is very flat and lies approximately 6 kilometers northeast of the City of Moorhead and about 10 kilometers from the plant. The topsoil is a Lacustrine silt and clay containing enough decomposed organic matter to make it dark brown to black. This type of topsoil on the flat terrain restricts runoff of the sludge and promotes infiltration into the soil.

Sludge is hauled throughout the year, since the ground is frozen enough in the winter to support the loaded truck. Plant personnel use snowplows to clear a path in the snow when necessary. In wet weather the sludge is held in an unheated secondary digester until it can be applied to the fields. In emergency situations old drying beds are available for dewatering the sludge. Application rates are about 5.56 m tons/ha/year. Currently, they do not have quantitative information about crop response. They have had no adverse community reaction and are pleased with their operations.

Over the past few years a much greater demand for the digested sludge has come about as more and more farmers in the Moorhead area want their land amended with the sludge. Soil samples were taken on the city-owned farmland in the fall of 1972 and analyzed by the staff at North Dakota State University. The results of these tests showed an increase in soil nutrients where the sludge was applied when compared with the nutrient status of no-sludge treated soils of the same type. The results are tabulated below:

No-sludge amendment	Sludge amendment
1972 Crop - soybeans	1972 Crop - summer fallow
Rate of appl. - none	Rate of appl. - 5.8 tons/hectare
pH - 7.3	pH - 7.2
Nitrogen (N) - 16.8 kilograms/hectare	Nitrogen (N) - 168 kilograms/hectare
Phosphorus (P_2O_5) - 53.9 kilograms/hectare	Phosphorus (P_2O_5) - 70.6 kilograms/hectare
Potassium (K_2O) - 583 kilograms/hectare	Potassium (K_2O) - 583 kilograms/hectare

Some typical operational cost data were available for the months of September and October, 1972. These are summarized below:

	Sludge hauled 10^3 m^3	Percent solids	Dry tons	Cost							$/ dry ton	$/ m^3
				Labor	Fuel	Maint.	Deprec.	Interest	Insurance	Total		
Sept.	3.44	1.84	63	721	93	125	242	114	26	1,321	20.80	.38
Oct.	3.59	1.44	51.7	724	118	125	242	114	26	1,349	26.09	.38

St. Cloud - The St. Cloud Wastewater Treatment Plant was designed for 13.2 x 10^3 m^3/day capacity but is being operated at between (24.6 to 32.2) x 10^3 m^3/day. The plant design includes primary and secondary (trickling filter) sedimentation. The plant lies south of town, so the truck does not go through the congested part of the city. Part of the sludge disposal city-owned site is leased to a private farmer at $12.35 per hectare plus a percentage of the crop. The city also purchased the necessary farming equipment (the cost of its use is incorporated in the lease cost to the farmer). Prior to the landspreading operation the site was barren farmland with extremely sandy soils. Since then, large amounts of sludge have been applied and incorporated into the soil and the site is now reasonably productive farmland.

The principal crops grown are corn, soybeans, and alfalfa. Crop response is very good without the use of supplementary fertilizers. The farmer had the highest soybean yield in the area in 1972. The corn yield was also excellent (an adjacent farmer tried to grow corn for silage but plants grew only 35.6 cm tall).

The wet weather is not much of a problem. Sandy soils are well drained. Under extremely wet conditions, the farmer plows furrows perpendicular to the road (the field slopes away from the road) and liquid sludge is unloaded into these furrows and plowed under at a later time. In winter the city uses a snowplow to make a path in the field wide enough for the

truck to dump the sludge. Often, there are .91 to 1.2 meters of snow on the frozen fields.

The equipment used is an International tractor (gasoline fueled) with 27.6-m^3 and 11.4-m^3 trailer tanks. Both tractor and trailer are equipped with tandem axles. Single axle units did not work out well. The 11.4-m^3 trailer is rarely used except when load limits are imposed on the roads. The landspreading operation is conducted by one full-time driver who is held responsible for the truck. The sludge normally contains 2.5 to 5 percent solids and is stored in an unheated secondary digester prior to being loaded into the trailer. About five 27.6-m^3 loads per day are spread on the farm in a normal 5-day work week.

The city will build a new 68-76 x 10^3 m^3/day plant on 2.8 hectares of the 122-hectare site so that future landspreading will be adjacent to the plant. They are very pleased with landspreading and have encountered no major problems. Prior to the adoption of landspreading in 1958, drying beds were used to dewater the sludge. Dewatering was slow because of cool, humid weather, and the sludge sometimes required years to reach the desired degree of dryness. Sludge removal by hand with shovels was necessitated by the glass covering of the drying beds. Inasmuch as this procedure was expensive and the dry sludge was spread on fields and a golf course anyway, it was decided to try liquid sludge spreading.

Ohio Plants

Defiance - This 15.1 x 10^3 m^3/day secondary treatment plant treats about 50 percent domestic wastes and 50 percent industrial wastes and has utilized landspreading for the disposal of anaerobically digested sludges (5-7 percent solids) for about 2 years. Approximately 151 m^3 week are hauled away by a contractor in two 15.1-m^3 tank trucks at a cost of \$1.72/m^3. Assuming an average of 6 percent solids, this amounts to about \$28.6/dry ton.

The liquid sludge is spread on a 31.6-hectare cattle pasture owned by the contractor. The tile-drained field located 16 kilometers from the plant has outlets to the Auglaize River. Plans are being made to monitor the underdrainage for fecal coliforms, phosphates, nitrates, and phenols.

The city has also purchased a 9.1-m^3 tank truck and has agreed to pay a local farmer \$1.66/m^3 to spread the sludge on his cropland. The plan includes monitoring of crop yields and soil response.

Lancaster - At this 38 x 10^3 m^3/day plant the sludges produced from primary and secondary (low-rate trickling filters) sedimentation are anaerobically digested. The liquid-digested sludge normally averages about 4.75 percent total solids (53 percent volatile) and has a pH value of

6.7-6.8. Domestic wastes were estimated to account for 80-85 percent of the sewage influent.

Landspreading has been practiced since 1961 on 25.9 hectares of farmland adjacent to the treatment plant. The land, purchased by the city for the disposal of liquid digested sludge, continues to be cultivated by a local farmer. Sand-drying beds were once used but were abandoned because of high costs and operational problems. A vacuum filter was installed, but similar problems with the vacuum filter led to the decision to adopt landspreading. The vacuum filter, however, is maintained in an operational state and utilized when weather conditions preclude landspreading. When the vacuum filter is used, the filter cake is stockpiled at the plant and made available to the public. If weather permitted spreading of all the sludge, some 12.6 m^3 would be applied via a 4.2-m^3 tank truck to the 25.9-hectare field.

During the nongrowing season, liquid sludge is applied to all 25.9 hectares at an annual application rate estimated to be about 11.1 tons/ha. During the growing season, however, sludge is applied to only 12.95 hectares, yielding an annual application rate of 22.2 tons/hectare. The remaining 12.9 hectares are farmed by a local farmer via the following rotation scheme. The center of the field is farmed one year with sludge applied to the perimeter area. During the following year sludge is applied to the center portion where the perimeter is farmed. Sludge application ceases on the portion to be farmed immediately after plowing.

In 1972, 6.5 hectares each of field corn and popcorn were planted. Since the city does not receive any income from this operation, no data were available on crop yields. It was reported, however, that the farmer produces a marketable commodity. It was also believed the farmer utilized supplemental fertilization, but no data were available on the amount or type used.

Operational monitoring at the site is not conducted and a sludge analysis beyond that mentioned above was not available. Furthermore, the costs of the landspreading operation are not recorded.

Plans are under way to upgrade and expand the treatment plant, and landspreading will be continued as the preferred means of sludge disposal.

Sidney - Anaerobically digested liquid sludges from this 7.6 to 10^3 m^3/day activated sludge plant have been spread on farmland for 14 years. Inflow to the plant was estimated to be about 50 percent domestic wastes and 50 percent industrial wastes, with the industrial input stemming from an aluminum ore reduction plant. The sludge normally contains about 3.5 percent solids and the following detailed sludge analysis was available. All values are in mg/ℓ.

TKN -	770	Mn -	16
NH_3 -	73	NA -	245
P -	3,300	Cr -	47
K -	62	Fe -	296
Al -	2,400	Ca -	960
Cu -	25	Zn -	148
Mg -	275	SO_4 -	26

They are presently experimenting with a Calgon polymer (WT 3000) to further concentrate the solids to 6 percent.

Presently, the landspreading operation is conducted by plant personnel using a 7.6-m^3 tank truck. The sludges are hauled to 11 farms located within 2 to 10 kilometers of the plant site, but they are presently seeking additional farmland. Soil and crop response data were not available, but some farmers are reported to have indicated increases in annual corn yields of about 1.74 m^3/hectare. About 34 x 10^3 m^3 of liquid sludge were hauled to farmland in 1972 at a rate of about 114 m^3/day. No exact cost accounting is conducted relative to the landspreading operation, but the plant superintendent estimated daily costs to be about $36.55/day. This figure reflects only labor and fringe benefits and fuel costs, as depreciation and maintenance costs were not available. Using these figures, 1972 hauling costs were about $10,965 or $9.19/dry ton of solids ($0.32/m^3). A contract hauler had been used occasionally at a rate of $1.06/$m^3$. The plant personnel had also tried sub-sod injection of the liquid sludge, but gave up this practice because (1) it was too slow, (2) if the soil is very stony the injectors would jump out of the ground, and (3) if the soil is frozen, sub-sod injection cannout be used. Spray irrigation was also suggested, but this method was rejected by the State EPA.

The plant and landspreading operations have been experiencing some bad public relations lately due to the construction of some expensive homes on the farmland above the plant and in and along the areas where sludge is being spread. They do not expect the problem to improve, thus they are seeking new landspreading sites. No pre- or postsite environmental studies have been conducted. However, prior to its use, each site must be checked and approved by a sanitarian from the County Health Department.

Springfield - Landspreading of liquid sludges has been used at this 94.6 x 10^3 m^3/day plant for the past 10 years. The sewage influent

is approximately 85 percent domestic wastes and the sludges produced by sedimentation and high-rate trickling filters are anaerobically digested. A typical sludge from this plant has a solids content of 8.6 percent (40 percent volatile) and a pH of 7.0. The plant has an operational vacuum filter, but it has not been used since landspreading was determined to be a cheaper and more easily managed sludge disposal method.

When the vacuum filter operation was discontinued, a 11.4-m^3 tank truck (diesel) equipped for gravity-flow discharge and spreader bar distribution was purchased and a special dock constructed to facilitate loading. The loading arrangement consists of a 10-cm counterweighted loading boom, an electrically operated switch located at the outlet for operator convenience and control, and a 2.65-m^3/min centrifugal pump to pump the sludge into the truck directly from the secondary digesters.

Through personal contact with local farmers and a news release in the local paper relative to the benefits of liquid digested sludge, adequate amounts of agricultural land were obtained for sludge disposal. At the present time, ten farms with land either in "soil bank" or planted in forage crops are available for sludge disposal on a rotating basis. The hauling distance to the farms most often used is approximately 16 kilometers round-trip, with the round-trip to other farms being about 29 kilometers.

During periods when weather does not permit landspreading, the sludges are disposed of in a 4.9 hectare lagoon located on the plant grounds. When dry, the sludge cake is removed for disposal in a city landfill. Data relative to the landspreading operation (i.e., costs, application rates, etc.) have not been routinely recorded to date. However, 6 years of records (1967-1972) were available for the amount of sludge spread on the land and the amount of sludge pumped to the lagoon. These records show that some 40 percent (41 x 10^3 m^3) were disposed of to the land while 60 percent (64 x 10^3 m^3) were lagooned.

In the absence of explicit operational data, some crude estimates of the cost of this landspreading operation were prepared using 4 years of data from the Springfield plant and operation and maintenance costs obtained from another landspreading operation which used a similar tank truck. These are summarized as follows:

Sludge hauled 10^3 m^3	Percent solids	Dry tons	Costs					$/ m^3	$/ dry ton
			Labor	Fuel	Maint.	Deprec.	Total		
24.9	8.6	2,359	12,056	536	2,400	4,384	19,376	0.58	9.05

Sludge application rate data were not available, as records are not kept regarding the amounts of sludge hauled to each site. No soil or crop response information was available, nor is any environmental monitoring of the site being conducted. Essentially, the truck driver and farmer use their own judgment as to the sludge applications.

Xenia - Landspreading of liquid sludges has been utilized by Xenia's two 3.8×10^3 m^3/day sewage treatment plants for about 13 years. Both anaerobically and aerobically digested sludges are being disposed of via landspreading. The sludges which are anaerobically digested at the Glady Run Plant are derived from primary and secondary (activated sludge) treatment operations. The Ford Road Plant sludges are from sedimentation from an activated sludge system.Typically, the sludges average about 2.3-3.5 percent solids (69-74 percent volatile) and have an average pH of 7-7.2. The sewage input to these plants is essentially 100 percent domestic wastes. Although a vacuum filter has been installed at the Glady Run Plant and provisions have been made for a vacuum filter at the new Ford Road Plant, landspreading of liquid sludges continues to be the method of disposal.

Presently, the sludge is spread on farmland used to grow field corn, wheat, and forage crops and on pastureland used for cattle grazing. During the growing season the liquid sludge is hauled extensively to pasturelands with the cattle remaining in the fields during the spreading operation. Thus far, only two farmers have complained about the sludge and discontinued its use. The reasons advanced for this discontinuance were that the sludge contained too many weed seeds and that the sludge killed the ants in the field. At the present time, ten farms are being utilized to receive the digested sludge. These farms were obtained primarily through advertisements in the local newspaper.

One full-time driver is employed to haul the sludges from both of the city's plants using an over-the-road tractor-trailer unit with a tank capacity of 11.4 m^3. This is a cumbersome unit for use in the fields so it frequently gets stuck and must be towed out with other city-owned equipment. Maintenance costs and driver qualifications are also higher for this type of unit than for operation of a normal tank truck.

The landspreading operation is conducted throughout the year. However, during adverse weather conditions the sludges are disposed of with no further attention on old sand-drying beds at an abandoned sewage treatment plant. Plant personnel conservatively estimated that 3.8×10^3 m^3 of sludge were disposed of in this fashion during the wet weather of 1972. The environs along the transportation route are essentially rural when hauling to the farmlands. However, when hauling to the abandoned treatment plant, the route is through the main business district and residential areas.

Two years of operational data were available and are summarized as follows:

	Sludge hauled 10^3 m^3	Percent solids	Dry tons	Costs					$/ m^3	$/ dry ton
				Labor	Fuel	Maint.	Deprec.	Total		
1971	8.69	3.5	304	7,696	236	271	2,400	10,603	1.22	34.89
1972	15.7	3.5	550	6,698	442	1,304	2,400	10,843	.69	19.72

No environmental site monitoring is conducted nor are data available relative to sludge application rates, soil and crop response, etc.

Zanesville - The sewage influent to this 94.6 x 10^3 m^3/day primary treatment plant is essentially 90 percent domestic wastes and 10 percent industrial wastes which stem from a metal plating firm and a slaughterhouse. The sludges are anaerobically digested and the solids content averages about 10 to 13 percent. Prior to the initiation of land disposal of the liquid digested sludge, a vacuum coil filter was utilized to dewater the sludge. The sludge cake was then stockpiled and made available free of charge to the general public.

The decision to utilize land disposal of the liquid sludge was made because of excessive maintenance problems associated with the coil filter in the form of stretching of the coils and, even more troublesome, problems associated with clogging of the filters with livestock hair from the slaughterhouse operation. Although operational, the coil filter has not been used since the landspreading was initiated. The filter well, however, is utilized to store digested sludge for transfer to a 6.1 m^3 tank truck which was purchased to transport and spread the sludge. A self-priming centrifugal pump mounted on the tank truck provides for both suction to fill the tank truck and pressure to discharge the sludge.

Various city-owned or leased sites such as municipal parks, football fields, abandoned city landfills, treatment plant grounds, and a 1.6-hectare weed field adjacent to the plant are used for the landspreading operation. Liquid sludge application to the park areas is restricted to the nonrecreational seasons and excellent grass cover was noted at all such sites. Occasionally, farmland or abandoned strip mine areas are also utilized. In fact, a very good example of land reclamation with liquid sludge was encountered here. About 3 years ago, approximately 3.8 x 10^3 m^3 of sludge were applied to a strip-mined area which was then seeded. Even with no further sludging, the area has continued to exhibit sufficient grass growth to support cattle grazing. One other attempt at land reclamation was noted in that grass seed was added to a load of liquid sludge and the mixture applied to an abandoned landfill. Although grass cover was obtained, this practice has not been utilized since.

The 1.6-hectare field adjacent to the plant receives approximately 75 percent of the plant's sludge output. Based upon an average of 4 years' data, sludge application rates to this field run about 309 tons/ha/year.

However, this is a sludge disposal operation, only, as the field does not produce a crop. Ready access to this level 1.6-hectare field enables the land disposal operation to be conducted throughout the year even in extremely wet weather conditions.

Four years of operational data for this land disposal operation are summarized as follows:

	Sludge hauled 10^3 m^3	Percent solids	Dry tons	Costs				$/ m^3	$/ dry ton
				Labor	Fuel	Maint.	Total		
1969	5.84	10.0	584	1,753	133	362	2,248	.39	3.85
1970	5.39	13.0	700	1,170	168	457	1,795	.33	2.57
1971	5.67	12.4	702	1,430	230	360	2,020	.36	2.88
1972	4.78	12.4	592	1,436	221	331	1,988	.42	3.35

No pre- or postoperational site monitoring is conducted, and data relative to an extensive sludge analysis and sludge application rates other than as estimated above are not recorded. The plant is presently being expanded and upgraded and the present plans call for a continuation of the land disposal activities.

Wisconsin Plants

Beaver Dam - The sludges produced by sedimentation and low-rate trickling filters are anaerobically digested at this 16.8 x 10^3 m^3/day plant. The sewage influent was estimated to be 70 percent domestic wastes and 30 percent industrial wastes. The liquid digested sludge normally contains about 6.4 percent solids (41 percent volatile) and has a pH value of 7.2-7.3. Prior to the use of landspreading, open-drying beds were employed to dewater the sludge, which was then given away to the general public. However, climatic conditions would not allow adequate drying and the decision was made to switch to landspreading for the disposal of liquid sludge.

Land was secured by personal contact with local farmers, or, in some cases, farmers would request the liquid sludge after observing the beneficial effects on other fields. The land utilized includes both pastureland and cropland. Soil and crop response data are not solicited from the farmers, nor is any environmental monitoring conducted.

A 5.7-m^3 tank mounted in the bed of a dump truck is used to haul and spread the liquid digested sludge. The truck is obtained from the City

Motor Pool as needed at a cost to the plant of $3/hour. The plant personnel try to spread the sludge within 8 kilometers of the plant.

Operational data available for 1971 are summarized as follows:

Sludge hauled 10^3 m^3	Percent solids	Dry tons	Truck rental costs	Labor costs	Total cost	$/$m^3$	$/ dry ton
3.91	6.4	250	1,707	2,077	3,784	.97	15.11

DePere - At this 11.4 x 10^3 m^3/day plant primary and waste activated sludges undergo anaerobic digestion prior to being disposed of via landspreading by a contract hauler at a cost of .11¢ / liter. The liquid digested sludge averages 3.6 to 3.9 percent solids (50-55 percent volatile) and has an average pH value of 6.9. While the influent to this plant is primarily of domestic origin, it has a high industrial BOD loading stemming primarily from a dairy products operation.

Prior to using landspreading, open sand beds were used to dewater the sludge. Increased sludge volumes and drying problems led to the decision to dispose of the sludge via landspreading in the liquid state. The contract hauler owns an 8.9-hectare field which includes a 4.45-hectare lagoon. When weather permits, the contractor spreads the liquid sludge on a 4.5-hectare plot which will eventually be planted in field corn. During those periods when weather does not permit landspreading (spring and winter months, primarily), the sludge is disposed of in the 4.45-hectare lagoon.

About 312 m^3 of sludge are hauled each week. A 20.8 m^3 tanker is used by the contractor to haul five loads/day, 3 days/week. This amounts to some 16.14 x 10^3 m^3/year (614 dry tons/year). At the rate of .106¢ /liter the cost of disposal would be $17,056/year or $1.06/$m^3$ ($28.66/dry ton).

It was reported that while the State Department of Natural Resources does not require operational monitoring of the site, it must approve the landspreading site prior to its use.

Kaukauna - This 9.46 x 10^3 m^3/day activated sludge plant treats essentially domestic wastes and has practiced landspreading of anaerobically digested liquid sludge for the past 3 years. The sludge from the primary clarifiers and the waste activated sludge from the final clarifiers undergo both primary and secondary digestion. The resulting liquid sludge averages 4.8 to 6.2 percent solids (42-50 percent volatile) and has a pH value of 7. A vacuum filter was previously used to dewater the sludge, which was then hauled to a landfill. Upon the recommendation of their consulting engineers, the plant management abandoned the vacuum filter

and now dispose of the liquid sludge on nearby farmland. A 3.8-m^3 gasoline tank truck was purchased and modified to haul liquid sludge by removing the tank partitions.

The landspreading sites are privately owned farms used to grow field corn and forage crops. Some pastureland is also used. This land was secured through personal contact with the local farmers. While no soil or crop response data were available, it was reported that tomato seeds contained in the sludge were an occasional problem to the farmers and that supplementary fertilizers were most probably used.

Only one complaint was expressed regarding the landspreading operation. On one occasion sludge was spread near a public park and children playing in the park area got into the wet sludge right after it was spread. Numerous complaints were received from the parents of those involved.

Under adverse weather conditions the sludge is disposed of in a sludge lagoon located on the plant grounds. For a normal year, however, about 80 percent of the sludge is spread on farms.

Some operational data were available for 1972 and are summarized as follows:

Sludge hauled 10^3 m^3	Percent solids	Dry tons	Labor cost	Fuel cost	Maint. cost	Total cost	$/$m^3$	$/dry ton
1.59	5.6	89	1,251	187	696	2,134	1.34	24.01

Oshkosh - Landspreading of liquid sludges was initiated at this 37.9 x 10^3 m^3/day plant in April, 1973, as an interim measure during construction of a new plant which is scheduled for operation in mid-1974. During this construction period only primary (chemically assisted) treatment was provided. Prior to initiating this temporary landspreading operation, sand drying beds were used to dewater the sludge. Construction activities have removed the sand beds, thereby necessitating landspreading as a means of sludge disposal.

SECTION XII

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